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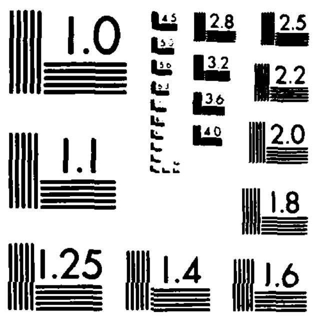

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STATISTICS OF INSTANTANEOUS RAINFALL RATES

Douglas M.A. Jones
Wayne M. Wendland

State Water Surveys Division
University of Illinois
Urbana, Illinois 61801

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The known sources of data from arrays of instantaneous precipitation intensity recorders were obtained. Data were obtained from Hohenpeissenberg, F.R.G.; East Central Illinois, U.S.A.; northeastern Illinois U.S.A.; and central Florida, U.S.A. These data were analyzed for line averages of the percent frequency of occurrence of exceedance of threshold precipitation intensities. The correlation coefficients of the precipitation intensity at sites at varying distances from a comparison site were determined and found to decrease with distance; the rate of decrease was an inverse function of distance and a function of the type

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20. of precipitation: showery or continuous. Showery rains were found to decorrelate about 12 km from the comparison site while continuous rains decorrelated near 50 km. Precipitation events had longer durations when the continuous rains were produced by cyclonic systems with some months experiencing measurable precipitation rates 20% of the time. Autumn tended to be the season with the least percentage of precipitation time.

Single-station intensity data collected at Urbana, Illinois, U.S.A.; Paris, France; Inyanga, Zimbabwe; Bogor, Indonesia; Reading, England, U.K.; Island Beach, New Jersey, U.S.A.; Miami, Florida, U.S.A.; Franklin, North Carolina, U.S.A.; and Majuro, Marshall Islands, were compared. The greatest precipitation intensity observed at any of these sites was 6.31 mm min^{-1} at Urbana. By comparison, the maximum rate in southern Germany was 0.32 mm min^{-1} and in Zimbabwe 5.08 mm min^{-1}.

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THE STATISTICS OF INSTANTANEOUS PRECIPITATION

by
Douglas M. A. Jones
and
Wayne M. Wendland

ABSTRACT

The known sources of data from arrays of instantaneous precipitation intensity recorders were obtained. Data were collected from Hohenpeissenberg, Federal Republic of Germany; East Central Illinois, U.S.A.; Northeastern Illinois, U.S.A.; and Central Florida, U.S.A. These data were analyzed for line averages of the percent frequency of occurrence of the exceedance of threshold precipitaton intensities. The correlation coefficients of the precipitation intensity at sites at varying distances from a comparison site were determined and found to decrease with distance; the rate of decrease was an inverse function of distance and a function of the type of precipitaton: showery or continuous. Showery rains were found to decorrelate about 12 km from the comparison site while the continuous rains decorrelated near 50 km. Precipitation events had longer durations when the continuous rains were produced by cyclonic systems with some months experiencing measurable precipitation rates 20% of the time. Autumn tended to be the season with the least percentage of precipitation time.

Single-station intensity data collected at Urbana, Illinois, U.S.A.; Paris, France; Inyanga Zimbabwe; Bogor, Indonesia; Reading, U.K.; Island Beach, New Jersey, U.S.A.; Miami, Florida, U.S.A.; Franklin, North Carolina, U.S.A.; and Majuro, Marshall Islands, were compared. The greatest precipitation intensity observed at any of these sites was 6.31 mm min-1 at Urbana. By comparison, the maximum rate in southern Germany ws 0.32 mm min-1 and in Zimbabwe 5.08 mm min-1.

INTRODUCTION

The objectives of this research were two-fold: 1) to gather an international data base of near-instantaneous precipitation rate measurements from meso-networks from various climate regions, 2) to investigate the correlation between near-instantaneous point precipitation rates from adjacent sites in the surrounding region as a function of increasing distance from the central site.

There is great interest in meso-scale precipitation rate analysis since precipitation intensity plays a critical role in many human indeavors, e.g., flood potential, construction code development, and microwave data transmission, to name a few. The first two are also sensitive to topography, surface material, etc. Microwave transmission is attenuated by an intervening water mass. Therefore, the spatial and temporal precipitation characteristics of areas are important information when estimating the maximum likelihood of successful data transmission under differing climatic and synoptic conditions. Not only do showers inhibit transmission between two line-of-sight transmission/receiving towers, but precipitation under and within a cloud can inhibit transmission between an earth station and satellites.

Climatologists, too, are interested in the temporal and spatial correlation of precipitation intensity under different synoptic and climatic regions. For example, although precipitation rates during short intervals of time would be expected to be greater during the summer than winter (since summer precipitation is primarily a function of cumulus activity as opposed to the large areal clouds and precipitation shields associated with synoptic scale cyclones), it is desirable to quantify the differences in precipitation rate in different climatic regions. In addition, precipitation events would be expected to be of shorter duration during summer than during winter, again because of the dominant cloud types with each season. Quantified estimates would help differentiate the precipitation characteristics of one climatic region from another. The degree of dissimilarity between interior continental and coastal stations, or mid- and low-latitude oceanic sites has not thus far been documented. Although one can hypothesize relationships on the synoptic climatology of any site in question, documented evidence is of great value to the hydroclimatologist to quantitatively describe areal precipitation differences.

Precipitation intensity data from several different sites in different climatic regions have been assembled in order to complete the objectives of this study. Specifically, data from seven areas were obtained including: 1) one site in Urbana, Illinois, U.S.A. (40°N latitude at 226 m msl), 2) 3 sites in Zimbabwe (20°S latitude between 1350 and 1900 m msl), 3) an Hawaiian data base (20°N latitude between 40 and 56 m msl) with 9 sites, 4) data from Hohenpeissenberg, F.R.G., (45° N latitude between 445 and 790 m msl) with 8 sites, 5) the Florida network near Kissimee (33° N latitude near 20 m msl) with 20 sites, 6) the East Central Illinois Network (ECI) with 13 sites located immediately west of Champaign, Illinois, U.S.A., (40° N latitude, 210 m msl), and 7) data gathered from an area in and about Chicago, Illinois, U.S.A., the CHAP Network (42° N latitude, 200 m msl) with 36 sites.

SITE DESCRIPTIONS AND RESULTS

Since the data were gathered at each of the seven areas by different research groups for different primary objectives, the array and density of pluviographs, the time period over which observations were made, and the type of pluviographs, themselves, may differ for each network. In addition, data from some of the sites were made available to this study only in reduced format, so that biases and prior stratification may have limited the usefulness of some of the site data relative to these overall objectives. These differences will be discussed below.

In general, data were sought from observing meso-networks with pluviographs capable of measuring precipitation rates at least at five minute intervals. The gages were oriented along a line or lines so that spatial correlation could be determined between the precipitation rate at a center (control) site and those further away.

URBANA, ILLINOIS USA

A weighing-bucket recording precipitation gage was added to the instruments at the Morrow Plots Climatological Station on the University of Illinois campus in 1949. The station is at an altitude of 226 m msl at 40 degrees 13 min N latitude and 88 degrees 13 min W longitude. The climate is humid continental with warm summers and cold winters, averaging 23.6C in July and -3.1C in January. Annual precipitation averages 912 mm with April through September storms contributing 63% of the annual total. Snowfall averages about 55 cm annually with very large variability (1-180 cm). The Illinois region is dominated by maritime tropical (mT) air from the Gulf of Mexico during summer and a mixture of mild Pacific air (mP) and cold, dry air from Canada (cA) in winter (Wendland and Bryson, 1981). During summer, mT air supports strong convection and relatively heavy, intense precipitation. During longer than normal summers, i.e., more weeks per year with mT air, these precipitation characteristics also prevail for a longer time. In general, the precipitation of warmer summers is characterized by a greater percentage of the annual precipitation being showery. Results found from Urbana data should be generally applicable to other mid-continent, mid-latitude sites which experience similar mixes of air masses.

In 1969 the weighing-bucket recorder was modified to obtain an expanded-scale analog chart by enlarging the collecting orifice by a factor of 2.5 and increasing the chart drive rotation speed by a factor of 4. These changes resulted in the recording of a centimeter of liquid as 2.5 cm vertically and one hour's record extending horizontally 48.7 mm on the chart. At this expanded scale one-minute precipitation accumulations may be obtained. The records from this open-scale instrument have been routinely digitized with a precision of 0.025 mm and the values stored on magnetic tape to facilitate subsequent analyses. In 1979 the precipitation recorder was returned to the physical state existing before 1969 to conform to the USA national standard since it is an official observation of this station, recorded in the publications of the US National Oceanic and Atmospheric Administration.

The first three years of the open-scale record were analyzed and described in the final reports of Contracts F19628-69-C-0070 and F19628-72-C-0052 with the U. S. Air Force Geophysical Laboratories (Sims and Jones, 1971, and Jones and Sims, 1973). The additional seven years of record have been digitized to determine the frequencies of precipitation intensities over the full ten year record, a unique data set for the United States. Slightly more than one percent (1.23%) of full operational time was lost because of recorder malfunctions. The average annual percent frequency that threshold intensities were exceeded for the ten years of record are given in Table 1 and in Fig. 1.

Fig. 2 shows the frequency at which measurable instantaneous precipitation occurs at 8 locations. The tables of frequency for these 8 sites were published in Jones and Sims (1971) and Sims and Jones (1973). Seven of the sites are in the northern hemisphere. Of these sites only Bogor, Indonesia, is south of the equator and only Majuro, Marshall Islands, is oceanic. Franklin, North Carolina, U.S.A., is in a mountainous area; all others are located in relatively low relief areas although the precipitation climate of Bogor is influenced by 3,000 m mountains on three sides. Several of these locations, Franklin, Reading, Miami, and Paris, for example, experienced drier seasons, but the tendency for all of these 8 sites to have a frequency of precipitation occurrence between 2% and 7% of the time in the month of July is notable. One would expect that a site such as Bogor south of the equator would experience a rainfall regime reversed from that of a site in the northern hemisphere with June, July, and August drier than other months when the Intertropical Convergence Zone is north of the equator. But, because of the link between the precipitation climate of Bogor with the mountains about the site, Bogor receives rainfall, mainly from thundershowers, from both the northwest and southeast monsoon circulations in all months of the year.

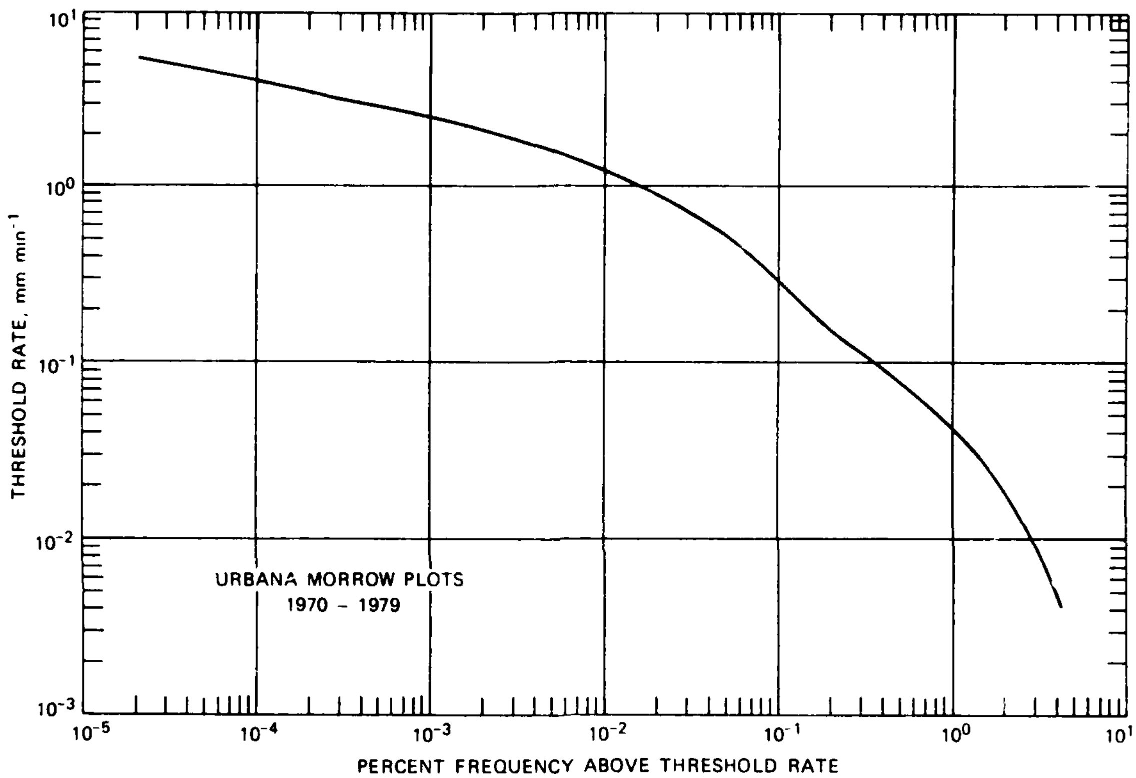

Figure 1. Cumulative frequency distributions of average rainfall rates for Urbana, Illinois, U.S.A., for a 10-year record, 1970-1979.

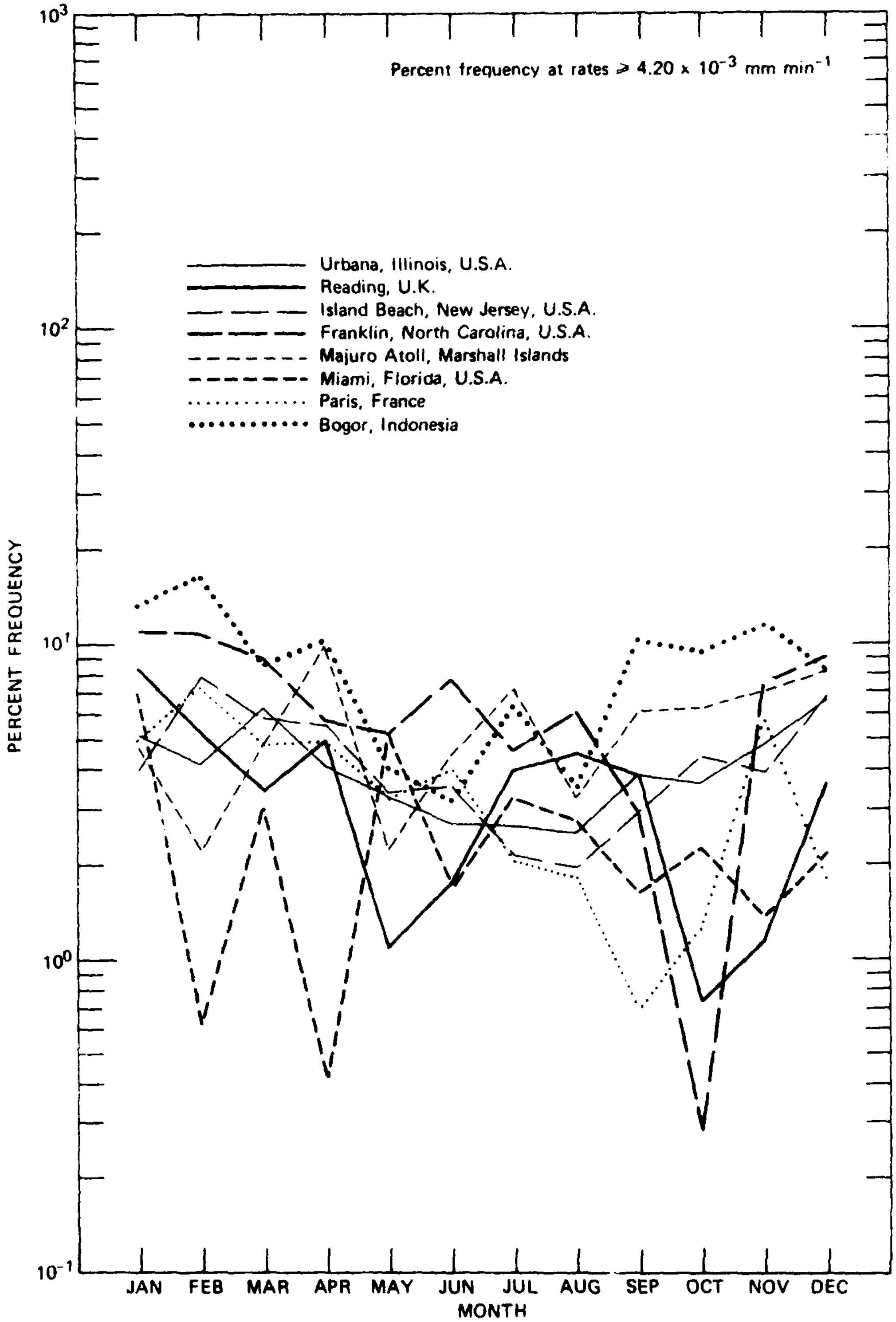

Figure 2. Percent frequency of occurrence at rainfall rates $>4.20 \times 10^{-3}$ mm min^{-1} at eight single-station sites.

TABLE 1

URBANA MORROW PLOTS 10-YEAR AVERAGE ANNUAL PERCENT FREQUENCY
OF EXCEEDANCE OF THRESHOLD PRECIPITATION INTENSITIES,
1970-1979.

Threshold Intensity mm min-1	Cumulative % Frequency of Occurrences	Threshold Intensity mm min-1	Cumulative % Frequency of Occurrences
6.31x10+00	1.93x10-05	1.26x10-01	2.53x10-01
5.01x10+00	1.93x10-05	1.00x10-01	3.51x10-01
3.98x10+00	1.16x10-04	7.94x10-02	4.88x10-01
3.16x10+00	3.08x10-04	6.31x10-02	6.51x10-01
2.51x10+00	8.66x10-04	5.01x10-02	8.37x10-01
2.00x10+00	2.08x10-03	3.98x10-02	1.05x10+00
1.58x10+00	5.01x10-03	3.16x10-02	1.29x10+00
1.26x10+00	9.03x10-03	2.51x10-02	1.57x10+00
1.00x10+00	1.62x10-02	2.00x10-02	1.86x10+00
7.94x10-01	2.59x10-02	1.58x10-02	2.18x10+00
6.31x10-01	3.75x10-02	1.26x10-02	2.53x10+00
5.01x10-01	5.21x10-02	1.00x10-02	2.89x10+00
3.98x10-01	6.93x10-02	7.94x10-03	3.24x10+00
3.16x10-01	9.05x10-02	6.31x10-03	3.57x10+00
2.51x10-01	1.15x10-01	5.01x10-03	3.90x10+00
2.00x10-01	1.45x10-01	4.20x10-03	4.14x10+00
1.58x10-01	1.87x10-01		

The average annual frequency of precipitation at Urbana was 4%, i.e., precipitation occurred 4% of the time, 363 hours per year. The monthly frequency of measurable precipitation is given in Table 2. In the mean, the month with the greatest number of minutes of precipitation time is December. The month with the least percentage of precipitaton time is August, but June, July, and August are about comparable. For individual months August 1971 had the least rain time (0.78%), 348 minutes, about 5 hrs, and March 1973 had the most observed precipitation time, i.e., 9.26% (4,134 minutes, about 69 hrs).

TABLE 2

AVERAGE MONTHLY FREQUENCY OF MEASURABLE PRECIPITATION
(>4.20X10-03 MM MIN-1),
URBANA.

Month	% Frequency
January	4.70
February	4.20
March	6.27
April	4.11
May	3.29
June	2.69
July	2.67
August	2.50
September	3.84
October	3.61
November	4.76
December	6.53

ZIMBABWE

Intensity of precipitation is measured routinely at a number of sites in Zimbabwe. A magnetic tape of the data derived from the analog charts of three sites (shown on Fig. 3) for a 5-yr period, 1976-80, were obtained from the Director, Department of Meteorological Services, Belvedere.

The precipitation climate of this region is characterized by a strong summer season maximum continuing from October through April, during which all of the annual precipitation is received. These sites receive virtually all precipitation through convective activity, i.e., showery precipitation, exhibiting relatively heavy rates with short duration. The sites are dominated by mT air from the Indian Ocean which lies to the east. The air experiences vertical motion and heating as it enters the continent. Even with the influence of topography, and the presence of mT air, this area does not experience the higher rain intensities observed within a highly continental environment at lower elevation (Battan, 1953).

Results from Zimbabwe should be applicable to subtropical latitude sites with near coastal locations invaded by mT air masses. Table 3 lists the altitude, latitude, longitude, and mean rainfall for the three sites.

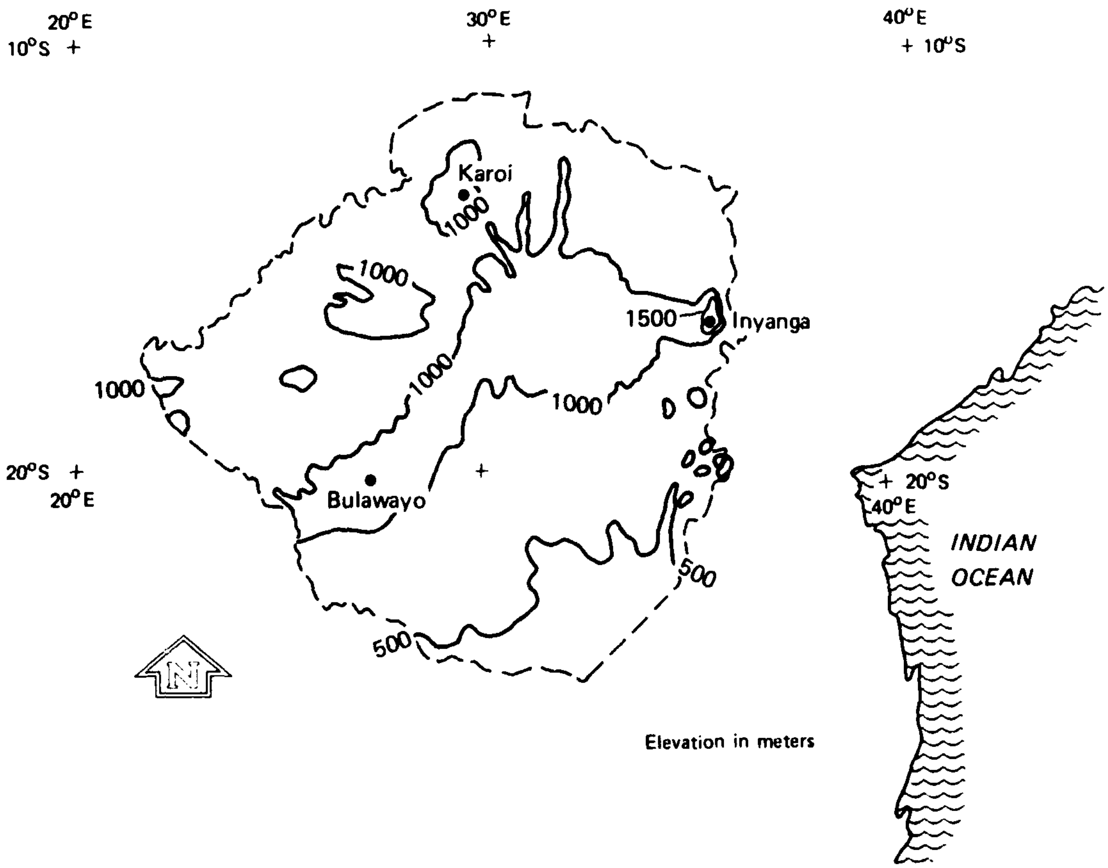

Figure 3. Topography and selected station sites in Zimbabwe.

TABLE 3

PHYSICAL DESCRIPTION OF SITES IN ZIMBABWE.

Site	Altitude, m	Latitude	Longitude	Average Annual Precipitation, mm
Bulawayo	1344	20°09'S	2°37'E	565
Karoi	1344	16°50'S	29°37'E	855
Inyanga	1878	18°17'S	32°45'E	1129

The precipitation intensity data available from Zimbabwe were recorded on Jardi-type instruments and only analyzed for durations of intensities greater than 25, 50, 75, 100, ..., 275, and 300 mm hr-1, with no intensities below 25 mm hr-1 tabulated. Since the recordings were analyzed for the number of minutes of rainfall above stated intensity thresholds, these thresholds are expressed in mm min-1 in this report. Thus, the threshold values are respectively: 0.417, 0.833, 1.25, 1.67, ..., 4.58, and 5.00 mm min-1. The maximum intensity recorded at the three sites during the 5-yr period was 5.18 mm min-1 at Karoi during December 1978. It is not known if this rate persisted more than one minute.

Since very light (0.417 mm min-1) precipitation intensities were not tabulated, there is no means available to determine the percent of time that rain occurred in any month. Integration of the amount of rain that fell at rates of 0.417 mm min-1 and above at Karoi results in an annual accumulation of 540 mm for the five years of analyzed record. Normal annual rainfall for Karoi is 855 mm which occurs on 88 rain days (included as information on the magnetic tape). Thus, about 315 mm per rainy season (37% of the annual total) falls at rates less than 0.417 mm min-1. Without the total rain percentage there is no way to determine the frequency of the lower rainfall rates. Similarly, the rain intensities above the minimum threshold at Inyanga account for 421 mm (38% of the annual total) whereas the average annual rainfall is 1120 mm occurring on 109 rain days. At Bulawayo the average annual rainfall is 565 mm occurring on 63 rain days, with only 340 mm (60% of the annual total) falling at rates of 0.417 mm min-1 or greater. The average rain day at Karoi receives 9.7 mm, at Inyanga 10.3 mm, and at Bulawayo 9.0 mm. At rates of 0.417 mm min-1 and greater Karoi has 6.1 mm per rain day, Inyanga has 3.9 mm, and Bulawayo has 5.4 mm. Thus, Inyanga at a higher altitude and closer to the Indian Ocean than the other two sites experiences more precipitation on the average. Karoi, at a lower altitude, averages higher intensities as well as experiencing the highest intensity of the three sites during the five years of record in agreement with the hypothesis of Battan (op cit.).

Table 4 lists the percent frequency of exceedance of threshold intensities at each of the three Zimbabwe sites.

TABLE 4

AVERAGE ANNUAL RAINY SEASON PERCENT FREQUENCY OF RAINFALL INTENSITIES >0.417 MM MIN-1 FOR THREE STATIONS, ZIMBABWE.

Threshold Intensity mm min-1	Cumulative Percent Frequency of Occurrence		
	Karoi	Bulawayo	Inyanga
4.17x10-01	2.31x10-01	1.68x10-01	1.10x10-01
8.33x10-01	6.76x10-02	5.52x10-02	4.47x10-02
1.25x10+00	3.10x10-02	1.65x10-02	1.79x10-02
1.67x10+00	1.33x10-02	4.11x10-03	9.95x10-03
2.08x10+00	4.85x10-03	7.44x10-04	2.49x10-03
2.50x10+00	1.38x10-03	2.72x10-04	8.52x10-04
2.92x10+00	4.58x10-04	1.38x10-04	3.28x10-04
3.33x10+00	1.97x10-04	1.38x10-04	1.31x10-04
3.75x10+00	1.31x10-04	6.90x10-05	6.56x10-05
4.17x10+00	1.31x10-04	6.90x10-05	
4.58x10+00	6.56x10-04	6.90x10-05	
5.00x10+00	6.56x10-05		

Table 5 displays cumulative percent frequencies for the two threshold levels, i.e., 0.417 and 0.833 mm min-1 for the months of the Zimbabwe summer rainy season (October-April). The absolute maximum and minimum frequencies for the five years of record by months are also shown.

TABLE 5

AVERAGE MONTHLY PERCENT FREQUENCY OF RAINFALL INTENSITIES
>4.17X10-1 MM MIN-1 AND >8.33X10-1 MM MIN-1
WITH MAXIMUM AND MINIMUM FOR EACH SITE,
ZIMBABWE.

	Cumulative Percent Frequency of Occurrence					
	>4.17x10-1 mm min-1			>8.33x10-1 mm min-1		
Month	Karoi	Inyanga	Bulawayo	Karoi	Inyanga	Bulawayo
Oct.	4.96x10-2	3.40x10-2	3.27x10-2	9.86x10-3	1.30x10-2	1.34x10-2
	1.81x10-1	8.51x10-2	5.82x10-2	4.93x10-2	4.48x10-2	20.0x10-2
		4.48x10-3				
Nov.	1.65x10-1	1.81x10-1	9.82x10-2	4.40x10-2	6.85x10-2	3.89x10-2
	1.88x10-1	4.84x10-1	1.46x10-1	5.79x10-2	1.99x10-1	5.09x10-2
	1.30x10-1	5.79x10-3	4.63x10-1	3.24x10-2		2.55x10-2
Dec.	3.21x10-1	2.44x10-1	1.44x10-1	8.94x10-2	7.95x10-2	6.90x10-2
	4.82x10-1	3.76x10-1	2.84x10-1	1.66x10-1	1.34x10-1	1.30x10-1
	2.42x10-1	9.34x10-2	3.36x10-2	5.60x10-2	2.16x10-2	6.72x10-3
Jan.	2.82x10-1	2.80x10-1	2.03x10-1	1.20x10-1	1.04x10-1	8.73x10-2
	4.82x10-1	6.19x10-1	3.56x10-1	1.81x10-1	1.72x10-1	1.79x10-1
	1.30x10-1	7.84x10-2	4.48x10-2	3.58x10-2	2.91x10-2	1.79x10-2
Feb.	4.28x10-1	2.55x10-1	2.16x10-1	1.14x10-1	7.18x10-2	7.80x10-2
	5.38x10-1	4.32x10-1	3.55x10-1	1.48x10-1	1.46x10-1	1.44x10-1
	3.35x10-1	3.68x10-1	2.23x10-2	8.18x10-2	1.23x10-2	4.96x10-3
Mar.	2.89x10-1	1.27x10-1	6.70x10-2	5.42x10-2	3.49x10-2	2.55x10-2
	6.81x10-1	2.40x10-1	1.77x10-1	6.72x10-2	5.82x10-2	8.96x10-2
	1.52x10-1	2.69x10-2		2.69x10-2	2.24x10-3	
April	9.72x10-2	7.05x10-2	1.20x10-2	4.44x10-2	1.76x10-2	6.47x10-3
	3.10x10-1	2.38x10-1	2.31x10-2	1.57x10-1	6.94x10-2	4.63x10-3
		1.03x10-2				

Order of entries: Average for month
Maximum for any year
Minimum for any year

Obviously, the two months at the beginning and ending of the rainy season, October and April, are the least likely to receive rainfall; April has a lower frequency of threshold rainfall than October.

Comparison of the three sites reveals that Karoi in northern Zimbabwe has a higher frequency of exceedance at these two rates of intensity in most months than the other two sites even though its annual rainfall is only 76% of the rainfall at Inyanga.

HILO, HAWAII

The Hilo site is dominated throughout the year by mT air emanating from the subtropical anticyclone over the eastern North Pacific Ocean (Wendland and Bryson, 1981). Because of its latitude (about 20°N), its location on the windward side of the mountainous island of Hawaii, an annual cycle in precipitation is apparent as an effect of annual migration of the Pacific subtropical anticyclone.

Virtually all precipitation is cumulus generated, much of it kept below the freezing level by the trade-wind inversion, i.e., a "warm" cloud. However, the showers are enhanced and spread out by orographic lifting along the upwind slopes. The intertropical convergence zone only reaches within about 1,100 km of Hilo in the mean, and then only for a short time in mid-summer.

Personnel of the Cloud Physics Observatory (CPO) of the University of Hawaii at Manoa developed a rainfall intensity gage which electrically measures the volume of precipitation down an inclined plane. Insufficient computer capacity prevented retention of all rainstorms sampled. Therefore only 57 storms were retained from collection over a four-year period, principally chosen for the occurrence of high rates (Fullerton and Wilson, 1975). Thus, the available record is not climatological in that the statistics do not include all events, but only a select subset. Further, the instrumentation is described by the developers (Fullerton and Wilson, 1975) as untrustworthy at intensities less than 10 mm hr-1.

The network of seven sites about the Observatory is shown in Fig. 4 with the topography of the area. It will be noted that the most distant site (K) was located only 312 m to the southwest of the control site (C). However, this short distance permitted the recording of the rainfall intensities without possibility of timing errors between the different sites. All sites were recorded at the Observatory on a magnetic tape with timing obtained from the computer clock. The closeness of the sites to each other and their synchronous control permit the greatest confidence to be placed in these data, compared to other sites of this report. The rainfall events occurred between 28 February 1973 and 22 June 1974.

Table 6 lists the percent frequency of rainfall rates above specified thresholds of network average rates for all sites. Rainfall rates are expressed in units of mm min-1. The table includes rates less than 1.67x10-1 mm min-1 (10 mm hr-1) only to indicate the percentage of rates that occur below this threshold.

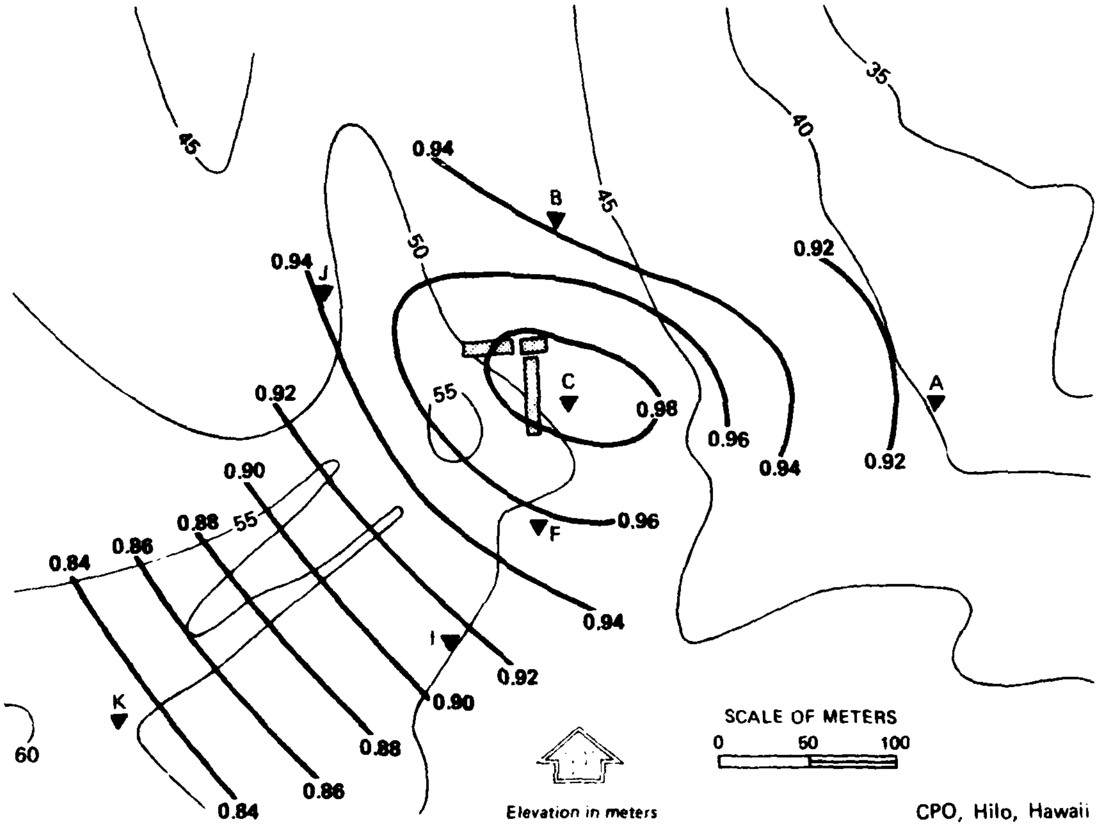

Figure 4. Topography, station sites, and correlation coefficients of concurrent rainfall rates of each outlying site with Site C, Hilo, Hawaii, U.S.A.

TABLE 6

PERCENT FREQUENCY OF EXCEEDANCE OF THRESHOLD RATES OF TOTAL RAIN TIME, HILO, HAWAII, U.S.A.

Threshold Intensity, mm min-1	Cumulative % Frequency of Occurrence	Threshold Intensity, mm min-1	Cumulative % Frequency of Occurrence
2.51x10+00	6.52x10-02	7.94x10-02	8.32x10+01
1.99x10+00	5.22x10-01	6.31x10-02	8.77x10+01
1.58x10+00	1.92x10+00	5.01x10-02	9.05x10+01
1.26x10+00	6.36x10+00	3.98x10-02	9.37x10+01
1.00x10+00	1.22x10+01	3.16x10-02	9.37x10+01
7.94x10-01	1.79x10+01	2.51x10-02	9.60x10+01
6.31x10-01	2.27x10+01	1.99x10-02	9.70x10+01
5.01x10-01	2.82x10+01	1.58x10-02	9.82x10+01
3.98x10-01	4.12x10+01	1.26x10-02	9.84x10+01
3.16x10-01	4.12x10+01	1.00x10-02	9.89x10+01
2.51x10-01	4.85x10+01	7.94x10-03	9.94x10+01
1.99x10-01	5.59x10+01	6.31x10-03	9.95x10+01
1.58x10-01	6.39x10+01	5.01x10-03	9.99x10+01
1.26x10-01	7.13x10+01	3.98x10-03	9.99x10+01
1.00x10-01	7.80x10+01	3.16x10-03	1.00x10+02

Table 6 shows that a rate of 2.51 mm min-1 occurred 0.065% of the time when rain was observed. One may further interpolate that reliable rainfall rates greater than 0.199 mm min-1 occurred 56% of the time. There were 3066 minutes of rain recorded from which these statistics are derived.

Another statistic that can be determined from the Hilo data is the correlation of the rainfall rate at each site with the rate at the same time at a designated control site. Site C at the Observatory was chosen as the control site with which the other sites would be correlated. The results are given in Table 7 and displayed in Fig. 4. As one would expect, the correlation decays with distance, but remains above +0.90 to a distance of about 200 m, and further decays to only +0.83 at slightly more than 300 m. Fig. 4 portrays the distribution of coefficients to show the spatial decay from the central site. The configuration of the correlation isopleths about the central site is not symmetrical, but tends toward a pattern elongated along the topographic contours as shown in the figure. The usual windflow with rain at the Observatory is from the ocean which lies northeast of the network.

TABLE 7

DISTANCES FROM SITE C AND CORRELATION COEFFICIENTS OF SITE INTENSITIES WITH THE INTENSITY AT SITE C, HILO, HAWAII.

Site	Distance from C, m	Correlation Coefficient
A	205	0.91
B	100	0.94
F	70	0.96
I	149	0.92
J	151	0.94
K	312	0.83

SOUTHERN GERMANY

The climate of this area is continental in nature although airstreams during most of the year are mP from the Atlantic Ocean, which dominates the Hohenpeissenberg area (latitude about 48°N) about 9 to 10 months per year. The remaining months (autumn) are dominated by Turkic air (cP source of mid-latitude Europe; Wendland and Bryson, 1981). The temperature climate of Germany is moderated by the mP air from the Atlantic Ocean, even though the moisture may have been depleted by precipitation on the continent. Annual mean precipitation is about 650 mm. South-facing slopes of the hills and mountains in the vicinity of Hohenpeissenberg should act as high-level heat sources to enhance the local instability for the generation of showers (Braham and Draginis, 1960).

An Ombroscope, an instrument to measure precipitation intensity, was developed by the personnel of the Hohenpeissenberg Observatorium of the Deutscher Wetterdienst, Federal Republic of Germany. The instrument determines intensity by counting the number of drops of equal mass passing a sensor in a precisely-determined period of time, in this case, one minute. Instruments were in operation between 1973 and 1974 at two sites, Raisting and Windachspeicher, with a third site added at Bischofsried in 1974 to establish a three- site line with a total length of 11.0 km northwest of Hohenpeissenberg near the Amersee. In 1979 five sites were established along the Isar River Valley from Hohenpeissenberg, past Munchen, to Weihenstephan. These lines are shown in Fig. 5. Table 8 lists the altitudes, latitudes, longitudes, and distances between the stations of the 3- and 5-site lines.

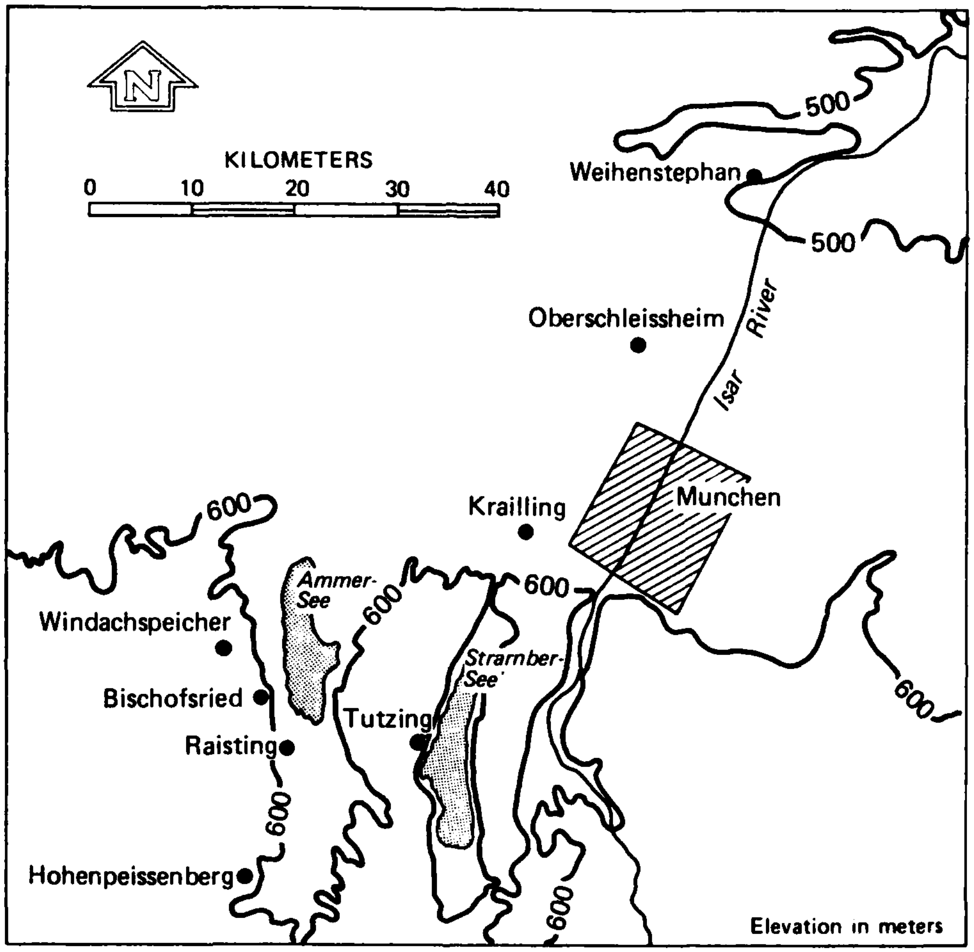

Figure 5. General topography and station locations in southern Germany.

TABLE 8

SITES, ALTITUDES, LATITUDES, LONGITUDES, AND DISTANCES FROM CONTROL SITES, SOUTHERN GERMANY.

3-Site Line

Site	Altitude m, msl	Latitude	Longitude	Distance from Raisting, km.
Raisting	570	47°54′N	11°16′E	0.0
Bischofsried	636	47°57′N	11°04′E	5.1
Windachspeicher	618	48°00′N	11°00′E	11.0

5-Site line

Site	Altitude m, msl	Latitude	Longitude	Distance from Krailling, km.
Krailling	560	48°06′N	11°25′E	00
Oberschleissheim	470	48°15′N	11°34′E	20
Tutzing	584	47°54′N	11°16′E	23
Weihenstephan	445	48°24′N	11°44′E	40
Hohenpeissenberg	790	47°48′N	11°00′E	45

It will be noted that the records from Raisting and Windachspeicher are all that are available along a 11.0 km line in 1973. The site at Bischofsried was added between the two existing sites in 1974 to complete a 3-site line. Table 9 lists the coefficients determined from the correlation of rates at Windachspeicher and Bischofsried with Raisting.

TABLE 9

CORRELATION COEFFICIENTS OVER THE 11 KM LINE, SOUTHERN GERMANY.

Site	Correlation Coefficient with Raisting	Period of Record	Distance from Raisting, km.
Windachspeicher	+0.01	28 July-18 Aug 1971	11.0
	+0.07	27 May-28 Aug 1972	
	+0.30	6 Nov-26 Dec 1973	
	+0.17	8 Jan-24 Mar 1974	
	+0.05	31 May-10 Sep 1974	
	+0.06	13 Oct-18 Dec 1974	
	+0.11	31 May-15 June 1974	
Bischofsried	+0.17	31 May-15 June 1974	5.1

The correlation coefficients between these sites indicate that there is no significant correlation in the statistical sense of these three sites during the period of study. This could result from either of the following: 1) There is no relationship in precipitation between these three sites or 2) the timing at the three sites was poorly synchronized.

An independent assessment of spatial correlation was made by correlating one-minute rates at Krailling with each of the other four sites from Hohenpeissenberg to Weihenstephan on the 5-site line. As one should expect, little correlation was found between these widely-spaced sites in the summer. Table 10 lists the coefficients of correlation by months for the 5-site line. Although there is little correlation in the summer months, correlation improves markedly in the winter months, reaching a maximum of 0.38, but explaining only 11% of the total variance.

TABLE 10

MONTHLY CORRELATION COEFFICIENTS OF CONCURRENT PRECIPITATION INTENSITY FOR FOUR SOUTHERN GERMANY SITES WITH KRAILLING.

Month, 1979	W	O	T	H
July	-0.01	+0.05	+0.04	+0.05
August	-0.03	+0.04	+0.08	+0.03
September	+0.24	+0.33	+0.23	+0.33
October	+0.41	-0.17	+0.22	+0.31
November	+0.11	-0.05	+0.27	-0.05
December	+0.31	+0.25	+0.13	-0.01
Month, 1980				
January	+0.23	+0.35	+0.37	+0.21
February	+0.33	+0.48	+0.34	+0.16
March	+0.04	+0.06	+0.05	+0.05
April	+0.18	+0.35	+0.25	+0.11
May	+0.04	+0.01	-0.02	-0.15
June	+0.11	+0.14	+0.24	-0.02
July	+0.03	+0.02	+0.14	-0.05
August	+0.00	+0.05	-0.00	-0.02
September	+0.01	+0.09	-0.02	-0.04
October	+0.34	+0.44	+0.38	+0.25
November	+0.13	+0.21	+0.21	+0.07
December	-0.21	+0.18	Insuf. data	+0.07

W - Weihenstephan
O - Oberschleissheim
T - Tutzing
H - Hohenpeissenberg

Line averages of the simultaneous 1-min precipitation rates for these five sites were calculated and are presented in Table 11. The line averages for the 3-site line are given in Table 12.

TABLE 11

LINE AVERAGE CUMULATIVE PERCENT FREQUENCY OF EXCEEDANCE OF THRESHOLD PRECIPITATION INTENSITIES ON 5-SITE LINE, SOUTHERN GERMANY.

Threshold mm min-1	July, 1979-80 Average Cumulative % Frequency of Occurrence	January, 1980 Cumulative % Frequency of Occurrence
3.16x10-01	2.26x10-03	
2.51x10-01	6.77x10-03	
1.99x10-01	1.80x10-02	
1.58x10-01	4.17x10-02	
1.26x10-01	8.57x10-02	
1.00x10-01	1.60x10-01	
7.94x10-02	2.32x10-01	
6.31x10-02	3.48x10-01	2.24x10-03
5.01x10-02	5.34x10-01	2.69x10-02
3.98x10-02	7.87x10-01	1.16x10-01
3.16x10-02	1.16x10+00	3.00x10-01
2.51x10-02	1.63x10+00	6.92x10-01
1.99x10-02	2.24x10+00	1.49x10+00
1.58x10-02	3.12x10+00	2.35x10+00
1.26x10-02	4.34x10+00	3.30x10+00
1.00x10-02	5.64x10+00	4.11x10+00
7.94x10-03	6.97x10+00	5.01x10+00
6.31x10-03	8.46x10+00	6.05x10+00
5.01x10-03	9.87x10+00	7.13x10+00
3.98x10-03	1.11x10+01	8.21x10+00
3.16x10-03	1.25x10+01	9.43x10+00
2.51x10-03	1.35x10+01	1.06x10+01
2.00x10-03	1.35x10+01	1.06x10+01
1.58x10-03	1.46x10+01	1.18x10+01
1.26x10-03	1.57x10+01	1.24x10+01
1.00x10-03	1.66x10+01	1.40x10+01
7.94x10-04	1.78x10+01	1.56x10+01
6.31x10-04	1.84x10+01	1.56x10+01
5.01x10-04	1.92x10+01	1.74x10+01
5.01x10-04	1.99x10+01	1.85x10+01

TABLE 12

THREE-SITE LINE AVERAGE RAIN INTENSITY CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE, SOUTHERN GERMANY, 1974.

Threshold Intensity mm min-1	Cumulative % Frequency of Occurrence	Threshold Intensity mm min-1	Cumulative % Frequency of Occurrence
7.94x10-01	1.51x10-03	2.51x10-02	2.71x10+00
6.31x10-01	3.02x10-03	1.99x10-02	3.37x10+00
5.01x10-01	1.06x10-02	1.58x10-02	3.99x10+00
3.98x10-01	1.81x10-02	1.26x10-02	4.71x10+00
3.16x10-01	3.77x10-02	1.00x10-02	5.45x10+00
2.51x10-01	6.79x10-02	7.94x10-03	6.18x10+00
1.99x10-01	1.06x10-01	6.31x10-03	7.05x10+00
1.58x10-01	1.71x10-01	5.01x10-03	7.55x10+00
1.26x10-01	2.58x10-01	3.98x10-03	8.23x10+00
1.00x10-01	3.65x10-01	3.16x10-03	9.24x10+00
7.94x10-02	5.16x10-01	2.51x10-03	9.55x10+00
6.31x10-02	8.08x10-01	2.00x10-03	1.09x10+01
5.01x10-02	1.14x10+00	1.58x10-03	1.09x10+01
3.98x10-02	1.60x10+00	1.26x10-03	1.19x10+01
3.16x10-02	2.15x10+00	1.00x10-03	1.30x10+01

A surprising result of the comparison of the frequency of precipitation represented by the smallest precipitation rate, 5.01 x 10-4 mm min-1 in Table 11, is that both January and July had measurable precipitation almost 20% of the total time. The 3-site line in its limited period of operation revealed that precipitation occurred 13% of the available time. The percent of precipitation time for the 5-site line decreased rapidly with increasing precipitaton rate as compared to the July percentage, i.e., the maximum rate in January (6.31 x 10-2 mm min-1) occurred for only one minute whereas the same rate in July occurred an average of 155 minutes. Thus, much more of the precipitation time was realized with higher intensities in July than in January even though the total precipitation time was about the same.

CENTRAL FLORIDA, U. S. A.

The Thunderstorm Project (Byers and Braham, 1949) operated a network of open-scale weighing-bucket precipitation recorders of the type operated in Urbana described earlier. The Florida network was operated in the vicinity of Kissimmee (28°18′N latitude, 81°25′W longitude, 20 m msl) from 19 May through 19 September 1946. The average spacing between sites was 1.6 km.

The airstream climatology of central Florida is a consequence of the combined influence of about 8 months dominance by mT air originating over the subtropical Atlantic, and 4 months dominance (October-January) of continental air (cP) originating in the Ohio River Valley (Wendland and Bryson, 1981). Although a continental source is present in fall and early winter, the close proximity of mT air even then (approximately 80 km east) produces mostly showery precipitation during the entire year.

The precipitation climate of Kissimmee is subtropical humid, with frequent sea breezes from the Atlantic Ocean converging with sea breezes from the Gulf of Mexico over the peninsula to trigger thunderstorms in the summer (Byers and Rodebush, 1948).

The records from two lines of sites were selected for analysis, i.e., intensity correlations with distance and line-average intensities. These two lines were the same as those analyzed by Sims and Jones (1975). The minimum time interval for determining precipitation rates was two minutes to reduce the boundary effects of timing errors inherent in the mechanical chart drives used in the instruments. The instruments were serviced every day. Thus, the intensities reported herein are identified as mm min-1 with the understanding that the rate was determined from a two-minute accumulation. Table 13 lists the site numbers, the distance from comparison sites, and the monthly correlations of the individual sites with their respective comparison sites. The spatial relationships of the sites to each other are shown in Fig. 6.

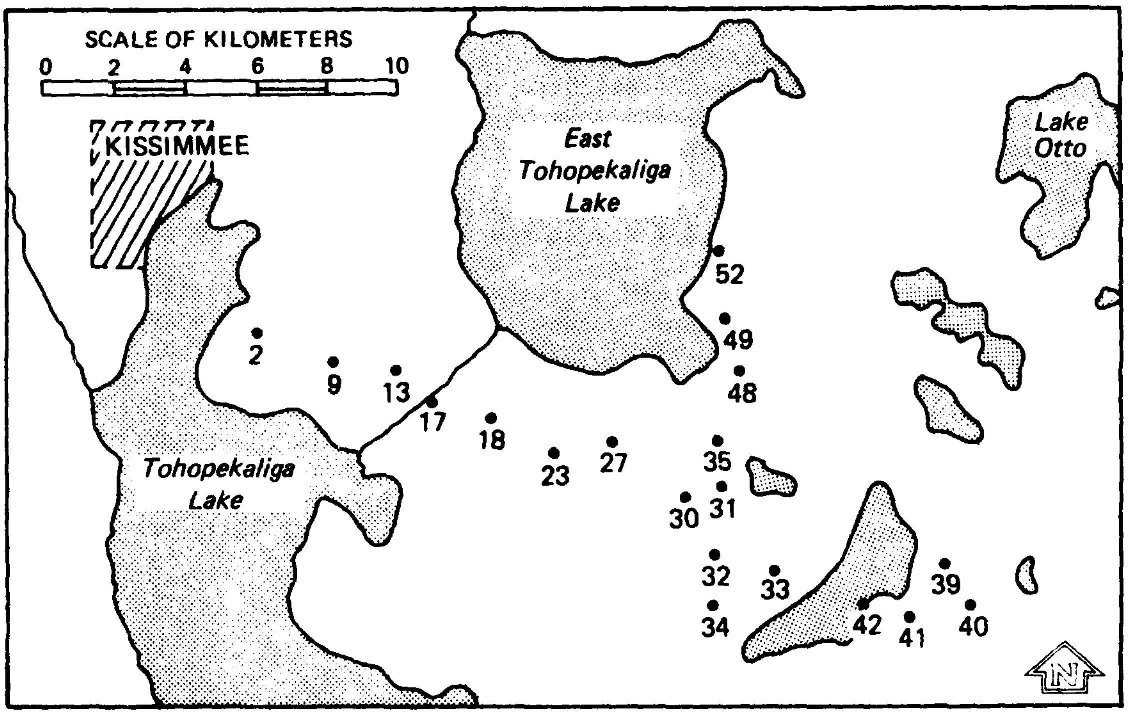

Figure 6. Central Florida selected raingage locations.

TABLE 13

FLORIDA RAINFALL RATE CORRELATION COEFFICIENTS AND DISTANCES, BY MONTHS, 1946.

a. North-South Line

Site No.	Distance from No. 35, km	Correlation Coefficients June	July	August
34	4.8	+0.25	+0.35	+0.07
32	3.2	+0.31	+0.36	+0.29
31	1.3	+0.58	+0.54	+0.52
48	1.9	+0.56	+0.50	+0.56
49	3.4	+0.29	+0.31	+0.48
52	5.1	+0.15	+0.20	+0.29

b. East-West Line

Site No.	Distance from No. 23, km	Correlation coefficients June	July	August
40	12.4	+0.04	+0.03	+0.01
39	11.3	+0.21	-0.01	+0.16
41	10.8	+0.37	-0.03	+0.04
42	9.0	-0.01	-0.03	+0.12
33	6.8	+0.07	+0.27	+0.13
32	5.1	+0.14	+0.31	+0.09
30	3.7	+0.20	+0.25	+0.20
27	1.6	+0.46	+0.48	+0.43
18	1.6	+0.68	+0.52	+0.61
17	3.4	+0.22	+0.47	+0.24
13	4.7	+0.09	+0.30	+0.16
9	6.4	+0.07	+0.25	+0.13
2	8.7	+0.04	+0.12	+0.03

Correlation coefficients to a distance of 2 km were between 0.43 and 0.68 during the three months of operation (June, July, and August); they declined to between 0.07 and 0.47 at 5 km, and exhibited essentially no correlation (+0.21, except for one value of +0.37) beyond about 10 km.

EAST CENTRAL ILLINOIS, U. S. A.

The East Central Illinois Precipitation Network shown in Fig. 7 was operated with 49 sites in a square grid pattern (about 830 km^2) in conjunction with radar studies. The analog recorders were identical to those used in the Thunderstorm Project (Byers and Braham, 1949), and the Urbana site between 1969 and 1979, i.e., an open-scale weighing-bucket precipitation recorder. Spacing between sites averaged 4.8 km. Only those sites that approximated N-S and E-W lines through the center of the network were used for correlation of intensity analysis and line-average rates. Latitude and longitude coordinates of the end sites are shown on Fig. 7. As with the Urbana site described above, the climate of the East Central Illinois Network is humid continental with cold winters and warm summers characterized by relatively large diurnal variation in temperatures associated with the frequent changes in air masses. About 60% of the annual total of precipitation falls in warm season convective precipitation. All of the data analyzed for this study were collected in April through August 1956 and April through October 1957, months generally limited to convective precipitation, but occasionally experiencing cyclone-associated over-running precipitation.

In order to limit the influence of timing errors between sites, the precipitation was integrated over 5 min, but reported as mm min-1. The 5-min integration interval was believed desirable since these sites were serviced after every precipitation event rather than on the regular daily service interval of the Thunderstorm Project.

Line average precipitation intensity was calculated for each 5-min interval and the cumulative percent frequency of exceedance of the threshold intensities determined. These are tabulated by months in Table 14.

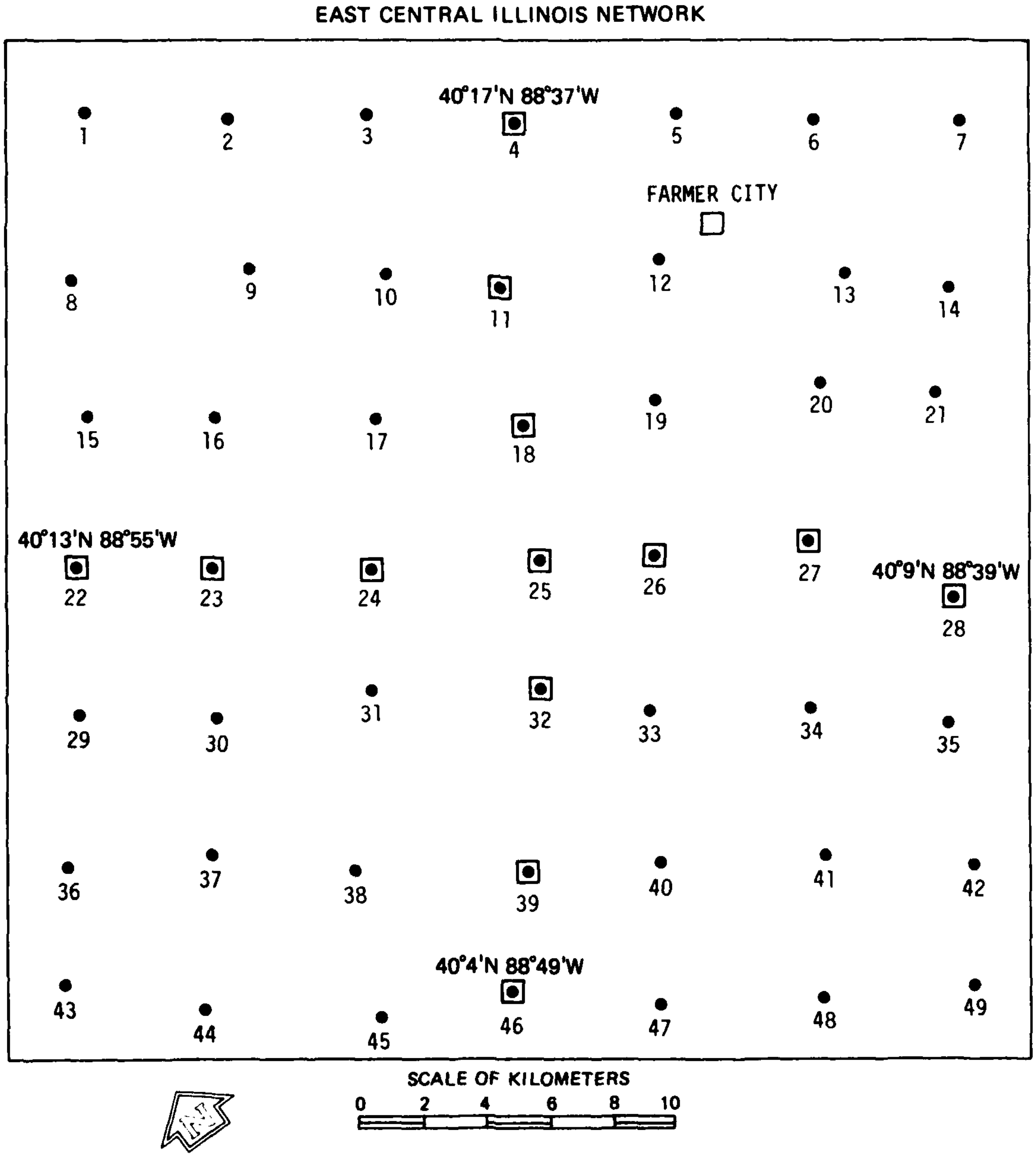

Figure 7. The East Central Illinois Raingage Network with selected gaging sites indicated.

TABLE 14

MONTHLY CUMULATIVE PERCENT FREQUENCY OF EXCEEDANCE OF LINE AVERAGE THRESHOLD PRECIPITATION INTENSITIES IN THE EAST CENTRAL ILLINOIS NETWORK, 1956-57 FIVE-MINUTE ACCUMULATIONS.

Threshold Intensity mm min-1	Cumulative Percent Frequency of Exceedance						
	April	May	June	July	August	Sept.	October
1.00x10+0			5.60x10-3				
7.94x10-1			1.40x10-3				
6.31x10-1	0.37x10-3	2.83x10-3	5.92x10-3	3.36x10-2	8.40x10-3		
5.01x10-1	3.49x10-2	1.98x10-2	1.48x10-2	4.76x10-2	3.08x10-2	5.79x10-3	
3.98x10-1	9.17x10-2	3.39x10-2	3.55x10-2	6.44x10-2	5.60x10-2	1.74x10-2	
3.16x10-1	1.83x10-1	5.37x10-2	6.51x10-2	9.80x10-2	1.01x10-1	4.15x10-2	
2.51x10-1	2.80x10-1	1.07x10-1	8.88x10-2	1.54x10-1	1.54x10-1	5.21x10-2	
1.99x10-1	4.37x10-1	1.92x10-1	1.54x10-1	2.16x10-1	1.85x10-1	1.16x10-1	5.60x10-3
1.58x10-1	5.63x10-1	3.31x10-1	2.46x10-1	3.11x10-1	2.55x10-1	1.79x10-1	8.96x10-2
1.26x10-1	7.77x10-1	4.41x10-1	3.28x10-1	3.64x10-1	3.11x10-1	2.31x10-1	2.02x10-1
1.00x10-1	1.12x10+0	5.77x10-1	4.68x10-1	4.82x10-1	4.28x10-1	3.01x10-1	3.42x10-1
7.94x10-2	1.44x10+0	7.75x10-1	5.42x10-1	5.68x10-1	5.40x10-1	3.82x10-1	5.15x10-1
6.31x10-2	1.70x10+0	9.62x10-1	6.72x10-1	6.92x10-1	7.31x10-1	4.22x10-1	7.67x10-1
5.01x10-2	2.08x10+0	1.17x10+0	8.32x10-1	8.76x10-1	9.60x10-1	4.80x10-1	9.63x10-1
3.98x10-2	2.51x10+0	1.41x10+0	9.77x10-1	1.04x10+0	1.18x10+0	5.32x10-1	1.21x10+0
3.16x10-2	2.97x10+0	1.67x10+0	1.17x10+0	1.23x10+0	1.42x10+0	6.19x10-1	1.56x10+0
2.51x10-2	3.49x10+0	1.97x10+0	1.33x10+0	1.42x10+0	1.66x10+0	6.94x10-1	1.94x10+0
1.99x10-2	4.03x10+0	2.30x10+0	1.46x10+0	1.61x10+0	1.89x10+0	8.28x10-1	2.40x10+0
1.58x10-2	4.52x10+0	2.64x10+0	1.61x10+0	1.80x10+0	2.12x10+0	9.78x10-1	2.79x10+0
1.26x10-2	5.13x10+0	2.94x10+0	1.75x10+0	2.02x10+0	2.28x10+0	1.09x10+0	3.26x10+0
1.00x10-2	5.91x10+0	3.28x10+0	1.92x10+0	2.20x10+0	2.46x10+0	1.28x10+0	3.83x10+0
7.94x10-3	6.69x10+0	3.68x10+0	2.09x10+0	2.40x10+0	2.58x10+0	1.47x10+0	4.29x10+0
6.31x10-3	7.49x10+0	4.00x10+0	2.31x10+0	2.60x10+0	2.76x10+0	1.66x10+0	4.65x10+0
5.01x10-3	8.12x10+0	4.34x10+0	2.48x10+0	2.80x10+0	2.93x10+0	1.87x10+0	5.01x10+0
3.98x10-3	8.73x10+0	4.66x10+0	2.60x10+0	0.97x10+0	3.10x10+0	2.04x10+0	5.25x10+0
3.16x10-3	9.43x10+0	5.03x10+0	2.80x10+0	3.13x10+0	3.30x10+0	2.30x10+0	5.47x10+0
2.51x10-3	9.93x10+0	5.37x10+0	3.00x10+0	3.30x10+0	3.45x10+0	2.51x10+0	5.78x10+0
2.00x10-3	1.06x10+1	5.73x10+0	3.24x10+0	3.53x10+0	3.64x10+0	2.71x10+0	6.00x10+0
1.58x10-3	1.12x10+1	6.07x10+0	3.52x10+0	3.78x10+0	3.76x10+0	2.89x10+0	6.17x10+0
1.26x10-3	1.20x10+1	6.34x10+0	3.69x10+0	3.96x10+0	4.01x10+0	3.12x10+0	6.33x10+0
1.00x10-3	1.25x10+1	6.73x10+0	3.89x10+0	4.21x10+0	4.28x10+0	3.33x10+0	6.52x10+0
7.94x10-4	1.30x10+1	6.94x10+0	4.26x10+0	4.40x10+0	4.49x10+0	3.62x10+0	6.73x10+0
6.31x10-4	1.35x10+1	7.18x10+0	4.67x10+0	4.80x10+0	4.69x10+0	3.74x10+0	6.88x10+0
5.01x10-4	1.40x10+1	7.44x10+0	4.93x10+0	4.96x10+0	4.92x10+0	3.91x10+0	6.98x10+0
3.98x10-4	1.46x10+1	7.73x10+0	5.19x10+0	5.34x10+0	5.09x10+0	4.10x10+0	7.22x10+0
3.16x10-4	1.50x10+1	8.02x10+0	5.35x10+0	5.49x10+0	5.21x10+0	4.17x10+0	7.34x10+0
2.51x10-4	1.52x10+1	8.19x10+0	5.51x10+0	5.59x10+0	5.28x10+0	4.21x10+0	7.41x10+0
2.00x10-4	1.56x10+1	8.35x10+0	5.94x10+0	5.91x10+0	5.35x10+0	4.31x10+0	7.70x10+0
1.58x10-4	1.57x10+1	8.41x10+0	6.25x10+0	5.98x10+0	5.37x10+0	4.36x10+0	7.73x10+0
1.26x10-4	1.59x10+1	8.47x10+0	6.37x10+0	6.18x10+0	5.40x10+0	4.55x10+0	7.75x10+0

It can be seen that April 1957 was indeed a rainy month. During that month precipitation occurred somewhere along the two orthogonal lines almost 16% of the time. In contrast, September 1957 experienced rain only 4.5% of the time. July was the month with the greatest line average intensity, i.e., a rainfall rate of 1.00 mm min-1 for a 5-min period averaged over 13 sites, along a linear distance totalling 28 km. Greater insight into the relationships of the frequency of specific intensities in the months analyzed may be gained by reference to Fig. 8 in which the monthly cumulative percent frequency of exceedance of four threshold precipitation intensities is presented. The curves of the four intensities portray essentially similar patterns (i.e., greatest frequencies of given intensities in spring and fall) except that the highest rate continues to decrease in frequency in October whereas lower rates increase in frequency. This infers that the October rains are less convective than those of spring and summer. Table 15 lists the 13 sites, their elevations above msl, the distance of each site from the central control site (No. 25) and the monthly correlation of concurrent precipitation intensities at each site with the intensity at the central site.

TABLE 15

EAST CENTRAL ILLINOIS NETWORK SITES, SITE ALTITUDES, DISTANCES FROM THE CENTRAL SITE, AND CORRELATIONS WITH THE CENTRAL SITE, 1956-57.

Site No.	Elevation m, msl	Distance from No. 25, km	Correlation Coefficients April	May	June	July	Aug.	Sep.	Oct.
4	230	13.4	0.32	0.31	0.08	0.31	0.48	0.36	0.61
11	230	8.4	0.50	0.46	0.15	0.30	0.59	0.35	0.42
18	226	4.2	0.54	0.33	0.57	0.43	0.58	I	0.49
22	230	14.0	0.43	0.37	0.10	0.32	0.26	0.11	0.46
23	237	10.0	0.50	0.44	0.30	0.48	0.39	0.15	0.51
24	228	5.1	0.43	0.56	0.41	0.68	0.49	0.25	0.60
25	222								
26	220	3.4	0.64	0.55	0.55	0.62	0.76	0.29	0.58
27	216	8.4	0.35	0.20	0.22	0.31	0.56	0.10	0.37
28	216	14.3	0.37	0.28	0.14	0.23	0.36	0.28	0.57
32	220	3.9	0.52	0.68	0.38	0.69	0.74	0.45	0.55
39	216	9.7	0.55	0.44	0.32	0.37	0.59	0.28	0.60
46	213	13.2	0.51	0.36	0.24	0.28	0.44	0.13	0.53

I - Instrument malfunction

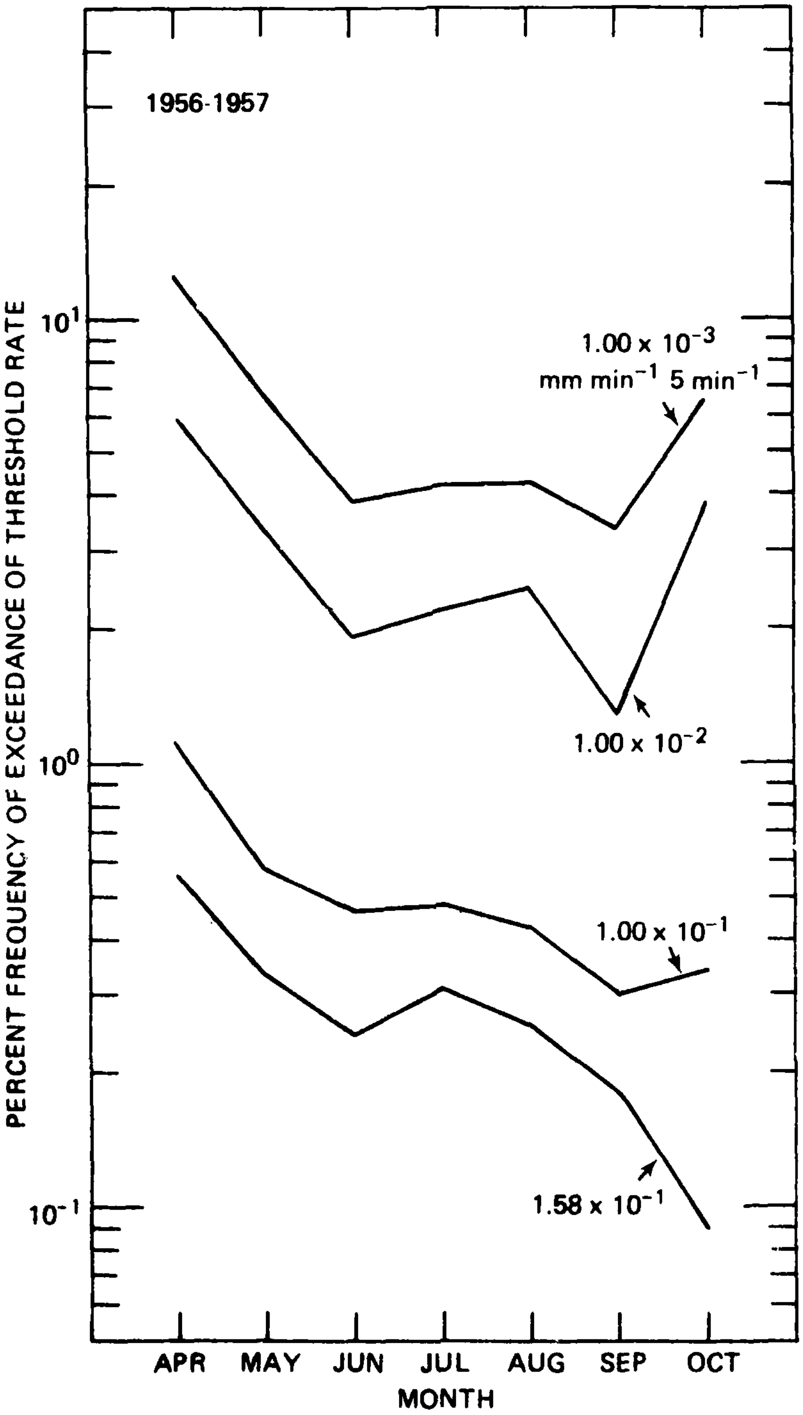

Figure 8. Monthly distribution of the percent frequency of exceedance of threshold rainfall rates at four selected rates on the East Central Illinois Raingage Network, 1956-1957.

Fig 9 is an illustration of the distribution for the summer months (June, July, and August) of the correlation coefficients of rainfall rate for each outlying site compared with Site No. 25 in the center of the network. Summer precipitation in east central Illinois is predominantly convective with southwest-to-northeast movement of the convective cells. This movement is apparent in the elongation of the pattern of coefficients in Fig. 9.

NORTHEASTERN ILLINOIS

The Chicago Hydrologic Area Project (CHAP) was designed to study the effects that this large metropolitan area and the large Lake Michigan to the east, have upon the precipitation climate of the region, and in turn, to determine a more reliable method of forecasting the distribution and amount of water to enter the Illinois Waterway. As an integral part of that program, 317 weighing-bucket precipitation recorders were installed about the southern end of Lake Michigan encompassing the city of Chicago and suburbs and a sufficient area upstream to the west to serve as a control. All sites in the inner portions of the network were on a N-S, E-W grid system with a mean spacing between sites of 4.8 km. Originally, the precipitation network was to be operated throughout the year for 5 years; however, the first winter's data so well proved the efficacy of the lake effect snow production that data gathering was not attempted in subsequent winters. Precipitation recorders were operated with the same timing interval and accumulation recording as the US standard recording gage, i.e., 1 mm of liquid equivalent precipitation is recorded as 1 mm on the vertical scale, and 1 hr of time as 12.17 mm horizontally. The network was serviced once each week; operation began in mid-June 1976 and terminated 30 September 1978.

The CHAP network is shown in Fig. 10 with the two lines of gages used in this study underlined, one east-west and the other north-south. The east-west line extended from 9 km east of Lockport, Illinois, to La Porte, Indiana, a distance of 104 km along the southern perimeter of Lake Michigan. Site No. 241 recorded on a compressed time scale chart and was not used in this study. The north-south line with 16 sites along the west side of the lake extended from Deerfield, Illinois, to 1 km west of Frankfort, Illinois, a distance of 72.3 km.

Tables 16 and 17 list the monthly north-south and east-west line average percent frequency of exceedance of threshold precipitation intensities. Because of the compressed time scale and the inability to accurately synchronize chart drives to accuracies better than about 2 minutes, precipitation intensities were determined for five-minute clock intervals, but reported as mm min-1. Of particular interest in these tables is the relatively high frequency of precipitation in April and August (1977) and October (1976).

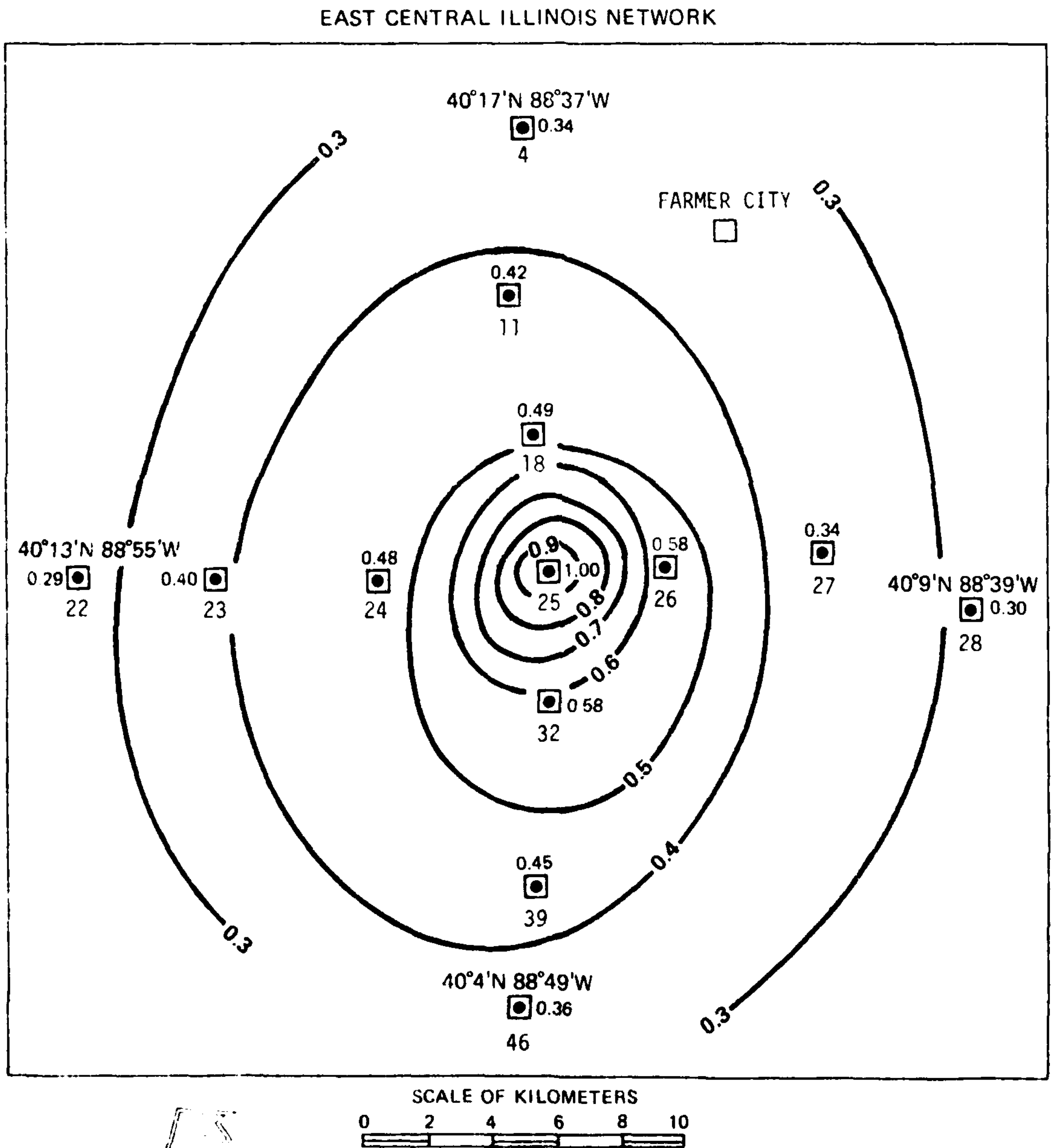

Figure 9. Correlation coefficients of rainfall rates of selected gaging sites with the centrally-gaged site, 1956-1957.

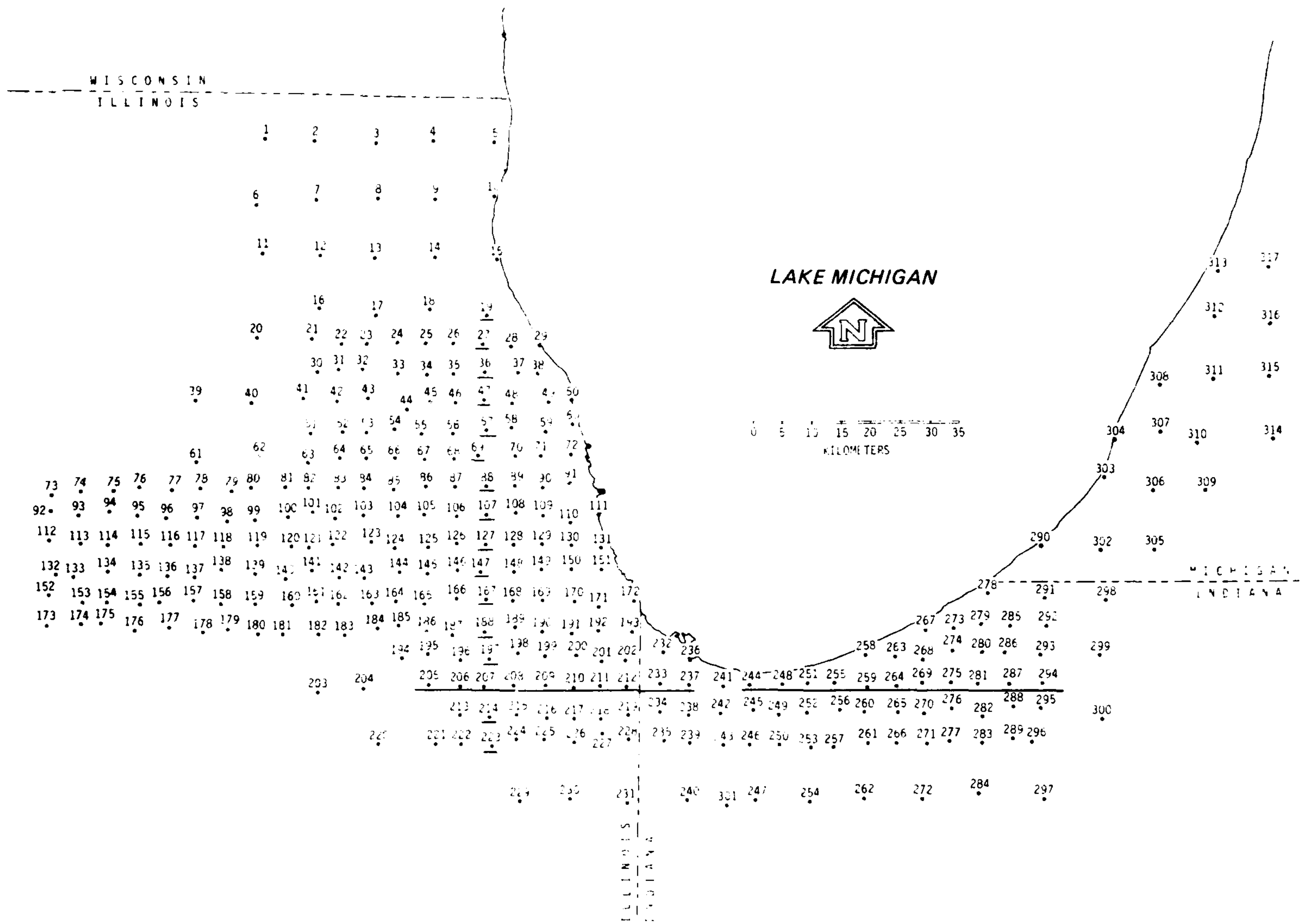

Figure 10. CHAP Network of northeastern Illinois and northwestern Indiana with analyzed sites underlined, 1976-1977.

Precipitation occurred more than 17% of the time on the north-south line and more than 18% on the longer east-west line in April and 23% in October. The eastern end of the east-west line extends into the shoreline area of Lake Michigan where summer and winter precipitation is affected by the lake. During June, July, and August the lake surface is colder than the air passing over the lake with the result that downstream activity tends to be suppressed for some distance over the adjoining land. Eventually, instability returns after the air has passed over the warmer land. During October of most years the lake surface is warmer than the air stream passing over it which destabilizes the air stream and adds moisture to it, resulting in more precipitation downstream of the lake than occurs upstream. Hence, the east-west line received more precipitation in that month than did the north-south line. April, May, and September tend to be transition months when the temperature of the airstream passing over the lake surface is about the same as the temperature of the lake surface.

TABLE 16

MONTHLY CUMULATIVE PERCENT FREQUENCY OF EXCEEDANCE OF LINE AVERAGE THRESHOLD PRECIPITATION RATES, FIVE-MINUTE ACCUMULATIONS, NORTH-SOUTH LINE, CHAP NETWORK, 1976-77.

Threshold	Percent Frequency of Exceedance						
Intensity	1977					1976	
mm min-1	April	May	June	July	Aug.	Sep.	Oct.
1.00x10+0			1.16x10-2				
7.94x10-1			1.16x10-2		1.12x10-2		
6.31x10-1			2.31x10-2		2.24x10-2		
5.01x10-1			5.79x10-2		3.36x10-2		
3.98x10-1		1.12x10-2	6.94x10-2		7.84x10-2		
3.16x10-1		1.12x10-2	1.50x10-1		1.01x10-1		
2.51x10-1	1.16x10-2	3.36x10-2	2.66x10-1	1.12x10-2	1.46x10-1		
1.99x10-1	2.31x10-2	4.48x10-2	3.70x10-1	3.36x10-2	2.24x10-1		
1.58x10-1	3.47x10-2	7.84x10-2	4.63x10-1	7.84x10-2	2.91x10-1		
1.26x10-1	1.04x10-1	1.46x10-1	6.25x10-1	1.46x10-1	4.28x10-1		
1.00x10-1	1.97x10-1	1.90x10-1	8.91x10-1	2.69x10-1	6.94x10-1	1.16x10-2	
7.94x10-2	3.01x10-1	3.25x10-1	1.20x10+0	3.81x10-1	1.12x10+0	2.31x10-2	
6.31x10-2	4.51x10-1	3.92x10-1	1.28x10+0	5.04x10-1	1.42x10+0	1.04x10-1	3.36x10-2
5.01x10-2	6.71x10-1	5.60x10-1	1.61x10+0	6.94x10-1	1.88x10+0	3.94x10-1	4.48x10-2
3.98x10-2	1.04x10+0	7.28x10-1	1.90x10+0	9.18x10-1	2.04x10+0	7.87x10-1	3.02x10-1
3.16x10-2	1.34x10+0	8.51x10-1	2.15x10+0	1.11x10+0	2.43x10+0	1.42x10+0	7.17x10-1
2.51x10-2	1.81x10+0	1.01x10+0	2.35x10+0	1.40x10+0	2.84x10+0	1.93x10+0	1.12x10+0
1.99x10-2	2.18x10+0	1.12x10+0	2.62x10+0	1.75x10+0	3.21x10+0	2.21x10+0	1.62x10+0
1.58x10-2	2.72x10+0	1.21x10+0	2.79x10+0	2.03x10+0	3.62x10+0	2.62x10+0	2.37x10+0
1.26x10-2	3.19x10+0	1.36x10+0	2.99x10+0	2.22x10+0	4.17x10+0	2.89x10+0	2.87x10+0
1.00x10-2	3.63x10+0	1.47x10+0	3.18x10+0	2.34x10+0	4.63x10+0	3.16x10+0	3.33x10+0
7.94x10-3	4.07x10+0	1.60x10+0	3.33x10+0	2.49x10+0	5.24x10+0	3.41x10+0	4.14x10+0
6.31x10-3	4.56x10+0	1.71x10+0	3.61x10+0	2.62x10+0	6.03x10+0	3.54x10+0	4.68x10+0
5.01x10-3	5.23x10+0	1.92x10+0	3.88x10+0	2.93x10+0	6.78x10+0	3.72x10+0	5.42x10+0
3.98x10-3	5.98x10+0	2.13x10+0	4.25x10+0	3.24x10+0	7.69x10+0	3.88x10+0	6.12x10+0
3.16x10-3	7.08x10+0	2.32x10+0	4.48x10+0	3.38x10+0	8.46x10+0	4.19x10+0	6.79x10+0
2.51x10-3	7.96x10+0	2.52x10+0	4.79x10+0	3.58x10+0	9.27x10+0	4.43x10+0	7.41x10+0
2.00x10-3	8.72x10+0	2.67x10+0	5.06x10+0	3.90x10+0	9.94x10+0	4.58x10+0	8.28x10+0
1.58x10-3	9.56x10+0	3.02x10+0	5.25x10+0	4.07x10+0	1.07x10+1	4.80x10+0	9.04x10+0
1.26x10-3	1.04x10+1	3.28x10+0	5.43x10+0	4.27x10+0	1.13x10+1	5.15x10+0	9.70x10+0
1.00x10-3	1.10x10+1	3.60x10+0	5.91x10+0	4.63x10+0	1.20x10+1	5.52x10+0	1.04x10+1
7.94x10-4	1.19x10+1	3.85x10+0	6.26x10+0	4.91x10+0	1.28x10+1	5.80x10+0	1.14x10+1
6.31x10-4	1.26x10+1	4.17x10+0	6.63x10+0	5.12x10+0	1.34x10+1	6.11x10+0	1.20x10+1
5.01x10-4	1.36x10+1	4.38x10+0	6.97x10+0	5.32x10+0	1.39x10+1	6.39x10+0	1.27x10+1
3.98x10-4	1.44x10+1	4.66x10+0	7.23x10+0	5.59x10+0	1.44x10+1	6.61x10+0	1.33x10+1
3.16x10-4	1.49x10+1	5.02x10+0	7.51x10+0	6.00x10+0	1.46x10+1	6.89x10+0	1.38x10+1

TABLE 17

MONTHLY CUMULATIVE PERCENT FREQUENCY OF EXCEEDANCE OF LINE AVERAGE THRESHOLD PRECIPITATION RATES, FIVE-MINUTE ACCUMULATIONS, EAST-WEST LINE, CHAP NETWORK, 1976-77.

Threshold	Percent Frequency of Exceedance						
Intensity	1977					1976	
mm min-1	April	May	June	July	Aug.	Sep.	Oct.
5.01x10-1			1.22x10-2				
3.98x10-1			3.66x10-2				
3.16x10-1			4.88x10-2				
2.51x10-1			8.53x10-2	1.15x10-2			
2.00x10-1		1.15x10-2	2.32x10-1	1.15x10-2			
1.58x10-1		3.46x10-2	4.14x10-1	9.18x10-2	2.49x10-2		
1.26x10-1	1.18x10-2	1.04x10-1	5.61x10-1	1.95x10-1	6.23x10-2		
1.00x10-1	5.92x10-2	1.61x10-1	6.46x10-1	2.53x10-1	1.62x10-1		
7.94x10-2	1.30x10-1	2.54x10-1	7.80x10-1	3.33x10-1	3.74x10-1	8.10x10-2	1.12x10-2
6.31x10-2	1.78x10-1	4.06x10-1	1.13x10+0	3.79x10-1	4.99x10-1	1.85x10-1	8.96x10-2
5.01x10-2	4.62x10-1	5.76x10-1	1.41x10+0	4.71x10-1	7.73x10-1	7.29x10-1	3.92x10-1
3.98x10-2	7.94x10-1	8.07x10-1	1.54x10+0	5.17x10-1	1.05x10+0	1.30x10+0	8.96x10-1
3.16x10-2	1.09x10+0	9.80x10-1	1.71x10+0	6.89x10-1	1.25x10+0	1.91x10+0	1.34x10+0
2.51x10-2	1.34x10+0	1.13x10+0	1.83x10+0	8.15x10-1	1.36x10+0	2.45x10+0	1.76x10+0
1.99x10-2	1.78x10+0	1.24x10+0	1.96x10+0	1.01x10+0	1.47x10+0	2.94x10+0	2.16x10+0
1.58x10-2	2.19x10+0	1.41x10+0	2.11x10+0	1.18x10+0	1.53x10+0	3.29x10+0	2.42x10+0
1.26x10-2	2.74x10+0	1.49x10+0	2.24x10+0	1.39x10+0	1.71x10+0	3.61x10+0	2.88x10+0
1.00x10-2	3.38x10+0	1.63x10+0	2.40x10+0	1.55x10+0	1.94x10+0	3.94x10+0	3.57x10+0
7.94x10-3	3.97x10+0	1.87x10+0	2.50x10+0	1.66x10+0	2.24x10+0	4.16x10+0	4.60x10+0
6.31x10-3	4.74x10+0	2.05x10+0	2.56x10+0	1.89x10+0	2.58x10+0	4.46x10+0	5.77x10+0
5.01x10-3	5.50x10+0	2.24x10+0	2.71x10+0	2.04x10+0	2.85x10+0	4.66x10+0	7.02x10+0
3.98x10-3	6.68x10+0	2.39x10+0	2.78x10+0	2.16x10+0	3.09x10+0	4.78x10+0	8.29x10+0
3.16x10-3	7.83x10+0	2.57x10+0	2.95x10+0	2.33x10+0	3.40x10+0	4.98x10+0	9.48x10+0
2.51x10-3	8.92x10+0	2.77x10+0	3.10x10+0	2.51x10+0	3.58x10+0	5.25x10+0	1.07x10+1
2.00x10-3	9.98x10+0	3.00x10+0	3.29x10+0	2.61x10+0	3.86x10+0	5.49x10+0	1.19x10+1
1.58x10-3	1.08x10+1	3.32x10+0	3.46x10+0	2.80x10+0	4.08x10+0	5.76x10+0	1.26x10+1
1.26x10-3	1.18x10+1	3.45x10+0	3.58x10+0	2.97x10+0	4.30x10+0	5.93x10+0	1.39x10+1
1.00x10-3	1.26x10+1	3.80x10+0	3.73x10+0	3.20x10+0	4.64x10+0	6.33x10+0	1.49x10+1
7.94x10-4	1.37x10+1	4.11x10+0	3.91x10+0	3.50x10+0	5.03x10+0	6.57x10+0	1.57x10+1
6.31x10-4	1.47x10+1	4.36x10+0	4.10x10+0	3.62x10+0	5.35x10+0	6.68x10+0	1.65x10+1
5.01x10-4	1.55x10+1	4.62x10+0	4.25x10+0	3.79x10+0	5.86x10+0	6.83x10+0	1.[illegible]9x10+1
3.98x10-4	1.59x10+1	4.75x10+0	4.61x10+0	3.95x10+0	6.17x10+0	7.18x10+0	1.87x10+1
3.16x10-4	1.62x10+1	4.99x10+0	4.79x10+0	4.03x10+0	6.27x10+0	7.33x10+0	1.99x10+1
2.51x10-4	1.67x10+1	5.08x10+0	4.92x10+0	4.07x10+0	6.52x10+0	7.52x10+0	2.03x10+1
2.00x10-4	1.70x10+1	5.11x10+0	5.02x10+0	4.11x10+0	6.70x10+0	7.66x10+0	2.10x10+1
1.58x10-4	1.72x10+1	5.26x10+0	5.08x10+0	4.12x10+0	6.80x10+0	7.77x10+0	2.22x10+1
1.26x10-4	1.74x10+1	5.30x10+0	5.39x10+0	4.21x10+0	6.94x10+0	7.88x10+0	2.23x10+1
1.00x10-4	1.75x10+1	5.43x10+0	5.40x10+0	4.33x10+0	7.00x10+0	7.89x10+0	2.28x10+1
7.94x10-5	1.77x10+1	5.45x10+0	5.40x10+0	4.40x10+0	7.02x10+0	7.89x10+0	2.30x10+1
6.31x10-5	1.78x10+1	5.60x10+0	5.40x10+0	4.43x10+0	7.04x10+0	7.92x10+0	2.33x10+1

Fig. 11 shows the percent frequency of exceedance of intensity thresholds for three representative intensities. Two values are shown for July and August since data were collected and analyzed during these months of both 1976 and 1977. The two values illustrate the interannual differences for these months as well as the different percentage frequencies for lines with orthogonal orientation. The north-south line averages are greater than those of the east-west line during the months with predominately convective precipitation, whereas the east-west line values tend to be greater during months when precipitation is large-scale cyclone induced. Lake Michigan diminishes the precipitation processes downwind of the lake in summer as mentioned earlier.

The highest reported intensity (1.00x10-1 mm min-1) increases from spring to summer, and decreases in the fall; the moderate intensity of 1.00x10-2 mm min-1 remains approximately constant in frequency in all months; and the lowest intensity (1.00x10-5 mm min-1) is most frequent in October. These observations are in accordance with the expected distribution of convective and wide-spread precipitation through the year.

Table 18 lists the north-south and east-west lines of recorder sites, their distances from the control site of each, and the correlation coefficients of concurrent precipitation intensity for each site with its comparison site. Within about 10 km of each control site there is some consistent correlation (generally, $r>0.20$); beyond that distance, the correlations are not consistent. As with other geographic areas where comparisons have been made, spatial correlations are greater during the months with greater frequencies of cyclonically-derived precipitation as opposed to convective precipitation.

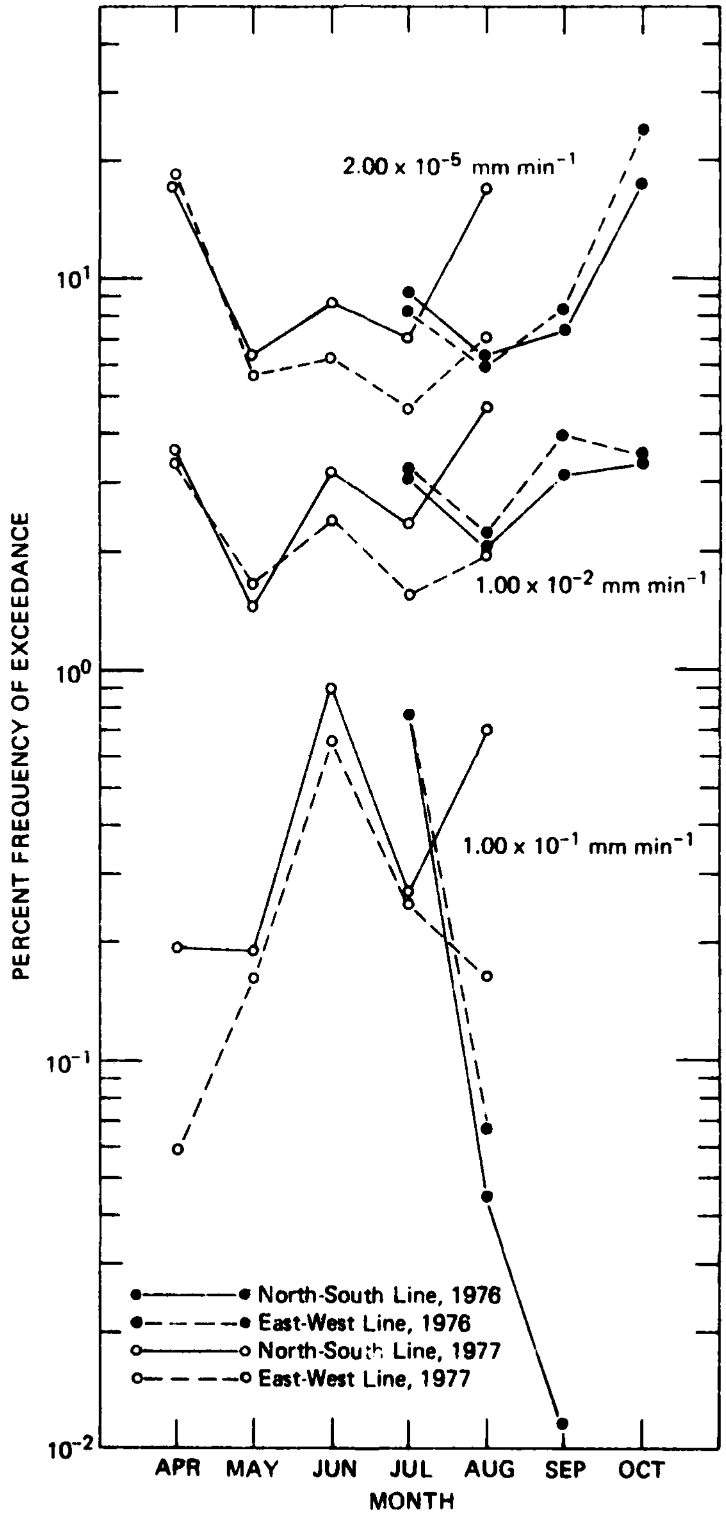

Figure 11. Monthly percent frequency of exceedance of three line-average rainfall rates for the north-south and east-west lines of sites on the CHAP Network for the years, 1976-1977.

TABLE 18

MONTHLY CORRELATION COEFFICIENTS OF CONCURRENT PRECIPITATION RATE FOR THE CHAP NETWORK, 1976-77.

a. North-South Line

Site	Dist. from No. 127 km.	July	Aug.	Sep.	Oct.	Apr.	May	June	July	Aug.
19	38.5	-0.00	-0.05	+0.20	+0.24	+0.03	+0.16	+0.12	+0.01	+0.21
27	33.7	-0.00	-0.02	+0.19	+0.17	+0.03	+0.19	+0.12	+0.04	+0.14
36	29.1	+0.08	-0.o2	+0.24	+0.19	+0.13	+0.39	+0.20	-0.00	+0.34
47	24.7	-0.06	-0.03	+0.34	+0.24	+0.28	+0.28	+0.20	+0.02	+0.34
57	19.5	+0.27	+0.11	+0.35	+0.20	+0.27	+0.17	+0.24	+0.14	+0.30
69	15.0	+0.09	+0.13	+0.37	+0.27	+0.37	+0.31	+0.31	+0.02	+0.30
88	10.0	+0.47	+0.17	+0.44	+0.43	+0.52	+0.39	+0.53	+0.03	+0.50
107	4.8	+0.38	+0.29	+0.59	+0.58	+0.59	+0.60	+0.60	+0.41	+0.71
147	4.6	+0.55	+0.43	+0.49	+0.49	+0.64	+0.61	+0.73	+0.77	+0.81
167	9.2	+0.35	+0.11	+0.44	+0.56	+0.52	+0.29	+0.47	+0.65	+0.52
188	14.8	+0.13	+0.16	+0.43	+0.40	+0.21	+0.35	+0.40	+0.15	+0.44
197	19.4	+0.02	+0.18	+0.27	+0.42	+0.27	+0.35	+0.40	+0.00	+0.35
207	24.1	+0.06	+0.11	+0.25	+0.32	+0.29	+0.14	+0.31	-0.01	+0.10
214	29.0	+0.02	+0.06	+0.18	+0.30	+0.02	+0.19	+0.19	-0.02	+0.51
223	33.8	+0.09	+0.08	+0.14	+0.33	+0.13	+0.27	+0.16	-0.01	+0.09

TABLE 18 (Cont'd)

b. East-West Line

Site	Dist. from No. 207 km.	July	Aug.	Sep.	Oct.	Apr.	May	June	July	Aug.
205	9.3	+0.57	+0.42	+0.74	+0.60	+0.21	+0.46	+0.91	+0.67	+0.21
206	3.8	+0.74	+0.64	+0.77	+0.77	+0.55	+0.47	+0.86	+0.59	+0.30
208	4.9	+0.70	+0.44	+0.73	+0.63	+0.42	+0.60	+0.31	+0.64	+0.09
209	10.6	+0.64	+0.23	+0.79	+0.51	+0.39	+0.13	+0.29	Insuf	+0.13
210	15.4	+0.47	+0.24	+0.60	+0.51	+0.15	+0.14	+0.24	+0.39	Insuf
211	19.9	+0.43	+0.14	+0.61	+0.40	+0.07	+0.24	+0.86	+0.25	+0.10
212	24.2	+0.34	+0.13	+0.52	+0.30	+0.04	+0.16	+0.15	+0.16	+0.12
233	29.7	+0.12	+0.06	+0.55	+0.23	+0.10	+0.15	+0.06	-0.00	+0.13
237	34.7	+0.20	+0.04	+0.42	+0.29	+0.05	+0.18	+0.03	+0.02	+0.19
244	45.0	+0.07	+0.02	+0.42	+0.46	+0.04	+0.10	+0.03	-0.02	+0.04
248	50.5	+0.09	-0.01	+0.38	+0.39	+0.06	+0.04	+0.00	-0.01	+0.01
251	54.7	+0.20	-0.01	+0.43	+0.50	+0.06	+0.07	+0.02	+0.18	-0.02
255	59.1	+0.19	Insuf	+0.30	+0.39	+0.08	+0.05	+0.06	+0.00	-0.04
259	64.8	+0.18	-0.04	+0.38	+0.37	+0.11	+0.00	+0.05	+0.02	-0.06
264	69.8	+0.20	-0.02	+0.22	+0.40	+0.07	+0.04	+0.05	-0.01	-0.08
269	73.9	+0.26	-0.05	+0.34	+0.33	+0.12	-0.02	+0.01	Insuf	-0.05
275	79.0	+0.41	-0.05	+0.27	+0.36	+0.15	+0.05	+0.03	-0.02	-0.04
281	83.1	+0.29	-0.06	+0.32	+0.40	-0.03	-0.02	+0.01	-0.03	-0.04
287	88.7	+0.25	-0.06	+0.27	+0.44	+0.11	-0.02	+0.01	-0.03	-0.05
294	94.3	+0.25	-0.08	+0.22	+0.41	+0.00	-0.02	+0.00	+0.05	-0.04

SUMMARY AND CONCLUSIONS

The wealth of precipitation intensity data was gathered for this project from tropical oceanic environments, subtropical lowland and montane regions, mid-latitude continental plains, and mid-latitude, and mid-continent montane regions. The value of this report rests upon 1) the fact that mesonetworks were establised and maintained by principal scientists in these different regions, 2) the climatic diversity of the observing sites, and 3) the free exchange of information between the principals. Although an experienced synoptic meteorologist would not be surprised at the relative differences found in precipitation from one climatic regime to another, the magnitude and differences in magnitude from place to place and through months of the year offer insight into precipitation climatology heretofore unknown.

The total duration of all precipitation events, regardless of intensity, is a function of dynamics, i.e., the mechanism whereby precipitation is produced and the frequency and availability of atmospheric moisture. Precipitation was experienced (West Germany) 19% of January 1980 and averaged 20% of July 1979 and 1980, roughly equal in all months of the year. In contrast, the minimum monthly precipitation duration experienced in the East Central Illinois network was 4% during one September and the greatest was 16% during one April. The relatively small analyzed data set from Paris, France, exhibited similar results to the monthly durations of Urbana, Illinois, U.S.A., i.e., longest precipitation durations during winter with the shortest durations observed during autumn.

The maximum intensity of precipitation ever observed at a specific site is another quantity which can be assayed from a study such as this. The heaviest precipitation intensities are typically associated with strong cumulonimbus development, a phenomenom often occurring on the American Great Plains where there is a juxtaposition of cP air converging with mT air. In accordance with this hypothesis, the greatest precipitation intensity observed at any site in this study was 6.31 mm min-1, at the Urbana site during June. The maximum intensity observed at Hilo was 2.51 mm min-1, and that from the CHAP network was 1.00 mm min-1, reported in June 1977. The greatest intensity reported for Zimbabwe was 5 mm min-1 whereas that in southern Germany was only 0.32 mm min-1, less than one-tenth of the greatest value. These numbers serve as a relative index of the mean intensity of cumulonimbus development in each of these various sites.

Line-average precipitation rates for all locales have been calculated where applicable and their frequency of occurrence determined. A line-average rate is a function of both the site-specific precipitation rate, the number of sites, and the distance between sites. A clear exposition of the relationships stated above is not possible in the data available; a long climatological record of line-average rates would be necessary to smooth away singularities along individual lines, even though the lines being compared shared the same precipitation climatology. At first glance the network about Chicago would fulfil the requirements to determine the relationships between line-average rate, line length, and number of sites. The north-south and east-west lines in northeast Illinois and northwest Indiana are in different precipitation climates because of the strong influence of the air streams from Lake Michigan, particularly on the longer east-west line. Notably, that east-west line with a total length of about 101 km had a maximum line-average rate of 0.501 mm min-1 in June 1977 whereas the north-south line with a length of about 72 km had a line-average rate of 1.00 mm min-1 in the same month. A simple ratio of the lengths of the two lines, 101/72 = 1.4, does not equate the east-west line rate to the north-south line rate. Other networks (ECI, Hilo, Florida, and Germany) had short line lengths and/or too short a record.

With the above discussion in mind, comparison of the maximum line- and area-average rainfall rates reveals that the CHAP Network had the values given above, the ECI Network had an area-average of 1.00 mm min-1 with an effective line length of 58 km, the Hilo network had an area-average of 2.51 mm min-1 with an effective line length of 0.85 km, and in southern Germany the 11-km line had a maximum average rate of 0.794 mm min-1 and the 85-km line had a maximum average rate of 0.316 mm min-1. The central Florida network line-average rates were reported in Jones and Sims (1971) where it was found that a 10-km line had a maximum rate of 1.99 mm min-1, another 10-km line had 1.58 mm min-1, and a 21-km line had 1.26 mm min-1.

The correlation between rainfall intensities at neighboring sites for the one-minute increments may be used as an index to gage the horizontal dimensions of the precipitation shield. Spatial correlation analyses were completed for the data sets from Hawaii, Germany, Florida, and East Central Illinois. The spacing of gages in Hawaii was limited to about 300 m. Correlation coefficients were greater than +0.90 for gage separations of up to 200 m, and declined to about +0.80 at 300 m. For Germany, correlation coefficients were generally less than +0.20 from spring through autumn, with maximum levels reaching about +0.3 in summer to distances of 11 km. In early summer (May and June) coefficients were about +0.15 to distances of 5 km.

The Florida array was about the same in horizontal extent as the 3-site line in Germany. In summer (June, July, and August) coefficients were between +0.43 and +0.68 to 2 km, between +0.07 and +0.47 to 5 km, and declined rapidly beyond, reaching essentially zero by 12 km, although there was substantial variation.

Because of the mass of data available from the CHAP network around Chicago, more specific comments can be made for this region. To a distance of 5 km, correlation coefficients were typically about +0.6 during spring, about +0.5 in fall and +0.3 to +0.6 in summer. To a distance of 10 km the correlations were reduced to +0.4 to +0.5 in spring, +0.3 to +0.5 in summer and about +0.4 in fall. Correlation coefficients from 20 to 40 km were reduced still further, e.g., 0.0 to 0.2 in all seasons. One must remember that the correlation coefficients of +0.6 at distance of 5 km explain only about 36% of the total variance.

The results presented above should be applicable to other sites located in similar precipitation climatic regimes, i.e., those with a similar mix of cumulonimbus versus widespread cyclonically-induced precipitation, depending upon availability of atmospheric moisture and the typical stability of the air masses over the sites in question. The above data provide a basis for decision-making for any activities which are (positively or negatively) impacted by the intensity, area and spatial coherence of precipitation events.

For similar spatial separation, correlation coefficients were largest in Illinois, somewhat smaller in West Germany, and much reduced in Florida. This trend suggests that a mechanism is operative to spread the area of approximately equal precipitation intensity in mid-continent that is not as effective in Florida. Mean cell diameters in Ohio and Florida were found to be the same during the Thunderstorm Project (Byers and Braham, 1949) which would eliminate cell size as the primary reason for the trend to larger coefficients away from the control site in Illinois. However, the Thunderstorm Project results did include a study of cell movement in Ohio and Florida. It was found that Florida cells moved with a mean speed of 16.7 km hr-1 and Ohio cells moved with a mean speed of 22.2 km hr-1. Thus, in Ohio the prevailing rainfall rate would tend to be spread downstream in less time than in Florida. Since Ohio and Illinois occupy the same latitude, continentality, and similar climate, the trend in coefficients with distance from the control site is explainable in Illinois by the spread of rates in cell movement when compared to Florida. However, it must be remembered that the time interval over which the rate is determined is another factor in the areal spread of higher coefficients. ECI network rates were determined from 5-min accumulations of precipitation whereas Florida rates were determined from 2-min accumulations. The longer interval will have the effect of reducing the highest observed rate and spreading equivalent rates over a larger area. Thus, a portion but not all of the difference in the trend of coefficients with increasing distance between Florida and Illinois may be explained by the differences in the speed of cell movement and the accumulation interval for the two regions.

One might ask how strong the relationship between the correlation coefficient and distance is under varying conditions of continentality, airstream origin, latitude, season of the year, etc. Unfortunately, the data are not available to provide the answers to all of these questions; more than one data set is necessary to answer each question. However, the seasonality influence may be determined from the data available. Fig. 12 is a scatter diagram of correlation coefficients of rainfall rates at varying distances from a comparison site for all of those data sets amenable to seasonal distribution. Ideally, one would plan an experiment which would have 70-km lines with spacing between sampling sites of 50 m. An alternative would be a logarithmic spacing interval starting about 50 m from the comparison site. Our approach to that ideal can be made by choosing all sites which may be separated into convective and continuous rain samples since these rain types are the characteristics of seasonality at mid-latitude sites. The convective rains are expected in mT air masses at Hilo and Miami throughout the year and at other sites in July. Continuous rains are usually associated with cyclones in the colder season and are approximated by the data for the month of October at mid-latitude sites in Germany and the U.S.A. These seasonal distributions are shown on Fig. 11. It will be seen that the convective samples tend

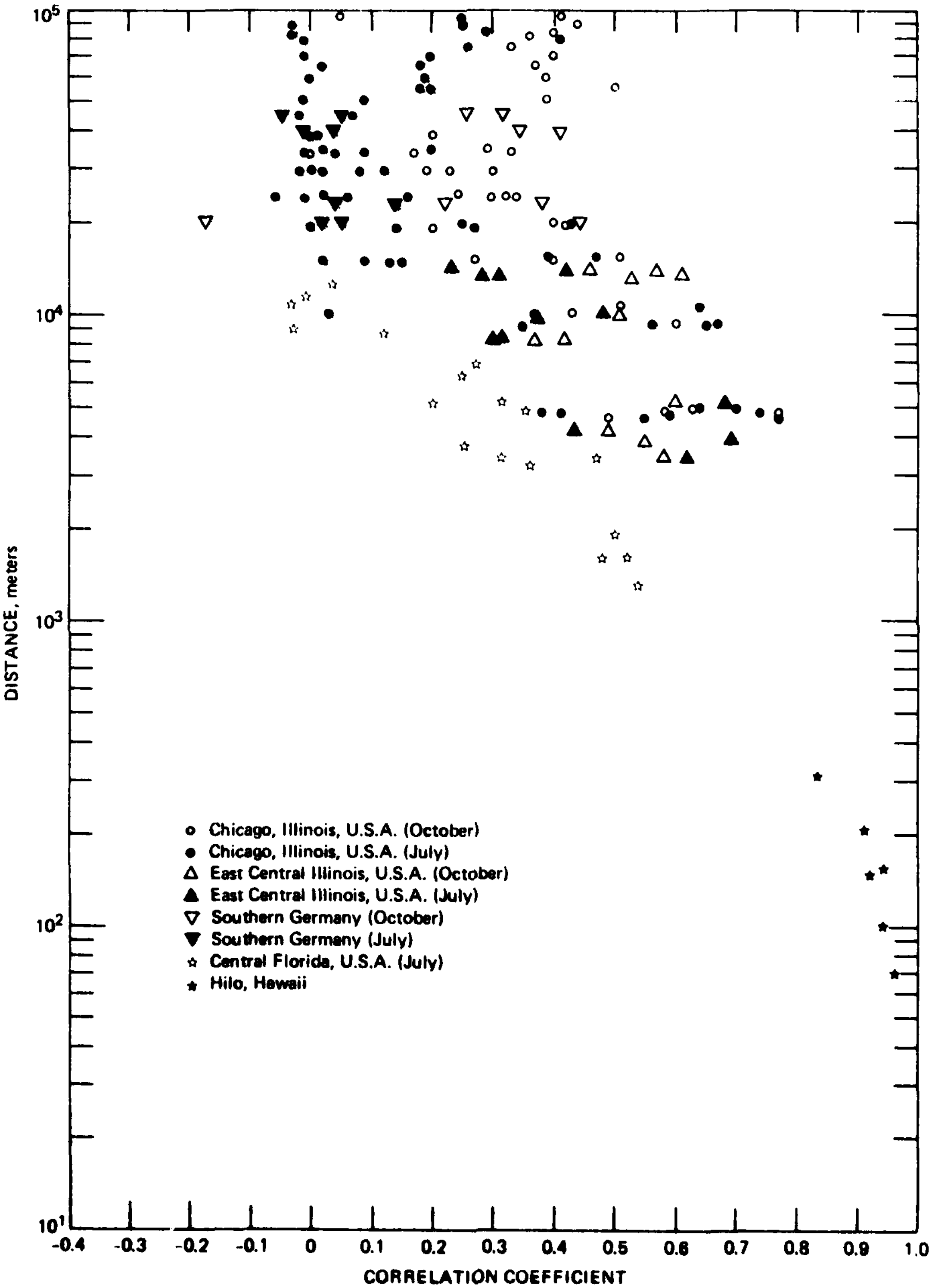

Figure 12. Correlation coefficients of rainfall rate at each site with the rainfall rate at a comparison site plotted at the distance from the comparison site.

to be confined to the left side or low coefficient side of the diagram and the October samples to the right side. There is more scatter in the October samples because the rains in October are a mixture of both convective and continuous types. Further, at distances greater than 20 km, the distance-coefficient relationship stabilizes, indicative of random correlation. Thus, there is a tendency for a boundary beyond which the coefficient does not increase for a given distance from the comparison site, terminating at zero correlation about 10-12 km distance. In the same sense there is a bound which limits the maximum value of the coefficient for a given distance in continuous rains, probably terminating near 50 km in random correlation.

Freeny and Gabbe (1969) approached the rainrate with distance problem by a different route, choosing to compare the joint probability of two stations at varying distances having a rainrate greater than a given rate. Their results showed the same conclusion as in this study, i.e., "a minimum in the joint probability when the stations are separated by about 12 km." Their study was confined to heavy rains in eastern New Jersey, U.S.A., between 1 June and 30 November 1967. Thus, the study did not include non-convective rains.

Percent of time that various precipitation intensities were exceeded was calculated from East Central Illinois, Zimbabwe, West Germany, Urbana, and Northeastern Illinois and are presented in Table 19. From 0.1 to 0.01 mm min-1, the percent times of exceedance are all of the same order of magnitude. The shortest durations were found for East Central Illinois. Data from West Germany exhibit substantially longer durations for precipitation intensities of 0.001 mm min-1 than do the ECI or the CHAP data, supporting the thesis that the montane region of southern Germany realizes more cyclonically-induced precipitation during all seasons than the North American Great Plains.

The general similarity of the times of exceedance regardless of location and precipitation climatology are indeed striking. If winter data had been more generally available, we suspect that more substantial differences would have been noted. The overall impression from the data of Table 19 is that times of exceedance of a specific threshold intensity (at least during spring, summer and autumn, and for the heavier intensities given in Table 19) are roughly equal, regardless of climatic region!

TABLE 19

PERCENT TIME THAT PRECIPITATION RATE EXCEEDED THRESHOLD.

Site	Exceedance Threshold (mm min-1) 1.0	0.1	0.01	0.001	0.0001	Period
Urbana	0.02	0.4	2.9			Annual
Zimbabwe	0.03	0.1				Oct-Apr Wet Season
West Germany		0.4	5.5	13.0		Annual
			4.1	14.0		January
		0.2	5.6	17.0		July
East Central		0.8	4.0	10.0	11.0	Spring
Illinois	0.006	0.5	2.0	4.0	6.0	Summer
		0.3	3.0	4.5	5.5	Autumn
Northeastern		0.2	2.0	6.0	10.0	Spring
Illinois	0.01	0.6	3.0	8.0	10.0	Summer
		0.01	3.0	8.0	10.0	Autumn

This analysis of precipitation intensity and spatial correlation of tropical and mid-latitude, oceanic and continental, and mountain and plains sites provides a quantitative evaluation for the degree of difference or similarity between them. Spatial correlations of one-minute precipitation rates were decidedly different, exhibiting the largest correlation coefficients during spring and autumn in mid-latitudes. The percentage of times that various precipitation intensities were exceeded were essentially equal from all sites and seasons with the exception that those of West Germany were greater for the less intense rates.

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